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Semi-Popular Articles

Utilization Abstracts

By the editor

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Wartime Cinchona Procurement in Latin America

In 1943 more than 7¾ million pounds of dry cinchona bark were imported into the United States from Bolivia, Peru, Ecuador and Colombia, and in the three years of 1943–1945 the wartime production of Peru alone amounted to over 4 million pounds.

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History

THE urgent need for the anti-malarial, quinine and related cinchona alkaloids in the prosecution of World War II was brought about by the early capture of Java by the Japanese. Java in the last half century has supplied approximately 95% of the world's quinine. All the far eastern cinchona plantations, principally in India and Java, originated from seed and seedling stock brought there only after much difficulty and sometimes in spite of hostile opposition during the past century from Andean South America. It was therefore obvious in 1942, with quinine supplies cut off, that the United States Government should initiate a wartime program of cinchona procurement in those Latin American countries where cinchona trees are native.

Some 30 cinchona alkaloids—including the all-important big four: quinine and its isomer quinidine, cinchonine and its isomer cinchonidine—are found in the bark of various species of the genus *Cinchona* (family Rubiaceae) whose natural distribution is known to extend from the mountains of southern Costa Rica and northern Panama, through the Andes of Colombia, Venezuela, Ecuador and Peru into Bolivia. Quinine also occurs in at least one related rubiaceous genus, *Remijia*, species of which occur in low mountain areas from Colombia to Peru; and alkaloids also occur sparingly in the bark of certain species of the genus *Ladenbergia* (cinchonine in Colombian *L. Hookeriana* (Wedd.) Standl. and in a Peruvian species which appears to be *L. malacophylla* Standl.), whose distribution parallels to a large extent its important cousin genus, *Cinchona*.

Although the natural range of cinchona species is extensive, spreading through approximately 30 degrees of latitude north and south of the equator and from sea level to the upper limits of tree growth around 11,000 feet, there are a number of sectors of the range where the trees are of little value. Thus

[1] Formerly (1943–1945) Botanist in charge of field surveys in Peru, Cinchona Mission, U. S. Foreign Economic Administration, Lima. Other North American botanists who aided in this wartime procurement program were:—W. H. Camp, N. Y. Botanical Garden (Ecuador); W. B. Drew, Michigan State College (Colombia, Ecuador); E. L. Evinger, USDA (Peru); J. Ewan, Tulane University (Colombia); N. C. Fassett, University of Wisconsin (Colombia); F. R. Fosberg, USDA (in charge of surveys in Colombia); F. M. Ownbey, State College of Washington (Ecuador); G. W. Prescott, Michigan State College (Ecuador); H. St. John, University of Hawaii (Colombia); W. C. Steere, University of Michigan (Colombia, later in charge of surveys in Ecuador); J. A. Steyermark, Chicago Museum (Ecuador, Venezuela); I. L. Wiggins, Stanford University (Ecuador). A number of US foresters shared equally in the work of the various surveys. Among them were:—L. R. Holdrige, USDA (Colombia); G. D. Fox and E. J. Rogers (Peru).

the botanical complex[2] of *Cinchona pubescens* Vahl, most wide ranging of the species, with representatives found at the extremes of range is largely an assemblage producing non-commercial barks.

It was inevitable then in World War II for the United States to attempt the procurement in those countries where the harvesting of cinchona bark had formerly been a long-established and commercially-profitable industry. In the order of the quality of barks produced, these countries were Bolivia, Peru, Ecuador and Colombia. The earliest exploitation of the cinchona tree was in the seventeenth century in the vicinity of Loja in southern Ecuador (a locality then included in the Viceroyalty of Peru, hence the early name "Peruvian bark") where typical varieties of *Cinchona officinalis* L. occur. During the eighteenth century new sources of cinchona bark, the "gray" cinchonine barks (*C. micrantha* Ruiz & Pav. and *C. nitida* Ruiz & Pav.), were located in the Huánuco region of central Peru by the first cinchona botanists, Ruiz and Pavon, who were sent out by the Spanish Government expressly to search for new sources of a commodity which was diminishing rapidly due to excessive exploitation of the so-called "Crown barks" in the old Loja region. A bit later other valuable species were discovered, the "red" barks (so-called *C. succirubra* Pav. ex Klotzsch) in what is present-day Ecuador, and of "Pitayo" bark (*C. pitayensis* Wedd.) in southern Colombia (then New Granada), and these served for a time to augment the supply. "Calisaya" (*C. Calisaya* Wedd.), one of the richest of all wild quinine barks, was the last of the important species to be discovered—in the early nineteenth century in Bolivia and southern Peru.

The pattern of ruthless bark cutting during the first half of the nineteenth century in the Andean cinchona-producing countries led to the successful attempt by the Dutch and the British to establish a plantation cinchona industry under their own control in the Far East where their heavily-populated colonies were dependent on unrestricted supplies of anti-malarials. With the establishment of these plantations and the accompanying improvement, as far as yields are concerned, in the species grown, the native Andean bark-cutting industries waned, partly due to the lack of demand but principally to the impossibility of competition between expensively-produced and alkaloid-poor native strains and cheaply-produced, alkaloid-rich, cultivated strains of cinchona. The year 1852 has been said to mark the beginnings of a shift from a forest to a plantation industry, a shift in production from the New World (Andean South America) to the Old World (British India). Yet a glance at Table I shows that as late as 1880, Colombia still was the principal world producer. But by the turn of the twentieth century production in Latin America was insignificant, and such bark cutting as existed at the time of World War II was largely for limited export to non-colonial European countries like Germany or for local use (Table II). The cessation in exploitation which has characterized most of the old cinchona centers since the beginning of the present century meant a natural repopulation of the cinchona forests which during the preceding two centuries had been temporarily depleted, and, except for a few centers in southern Peru and Bolivia in which especially high yielding species are

[2] The nomenclature of the genus *Cinchona* is complex and difficult, and up to the recent war years was considered "impossible" because of the innumerable forms and hybrids occurring in nature. The extensive collection of specimens and field observations brought together during the last few years give promise of bringing some order out of chaos. Monographic studies are, however, still incomplete, and nomenclature used in this paper can be considered only as tentative.

TABLE I

EUROPEAN IMPORTS OF CINCHONA BARK (IN POUNDS)*

Country of origin	1880	1911
Colombia	6,000,000	35,200
Bolivia, Peru, Ecuador	950,000	
India	1,170,000	458,600
Java	70,000	19,778,000
Jamaica	21,000	
Africa		25,400

* Table from Pan American Union, Washington.

located, wartime surveys found forests again stocked with cinchona trees.

In April of 1942 quinine procurement was placed in charge of the Board of Economic Warfare, a United States Government wartime agency which had charge of the accumulation of many strategic materials. This agency later became the Office of Economic Warfare and finally the Foreign Economic Administration. The Board of Economic Warfare broke its procurement problem into three plans: 1) a procurement plan under which all available stands of wild commercial cinchonas were to be obtained under a price schedule which would establish a fair and possibly permanent business; 2) a development plan for the formation of a permanent plantation cinchona industry in the Western Hemisphere, an industry to endure against the competition of the monopolistic Dutch Kina Bureau or of any other group, and an industry which would thereby insure this hemisphere against any future emergency; and 3) a training plan under which our agricultural scientists would train Latin American scientists so that the latter could continue the plantation program in their home countries.

So-called cinchona agreements were soon negotiated with the principal cinchona-producing countries of a century ago. In essence these countries agreed to give us sole buying privileges for all cinchona bark, provided we guaranteed 1) to buy all barks produced above a fixed minimum total crystallizable alkaloid content (this varied from 2–3% minimum), 2) to give technical aid in cinchona exploration and procurement, and 3) that we establish a cinchona plantation program. Due to the vicissitudes

TABLE II

WORLD PRODUCTION OF CINCHONA BARK IN THE PERIOD 1929–1938*

Country	1929	1932	1936	1937	1938
Latin America:[1, 2]	Quantities (1000 pounds)				
Bolivia	303	400	1,964	2,132	1,950
Peru	16	186	146	223	185
Ecuador	—[3]	61	170	162	—[3]
Colombia		4	27	119	2
Totals Latin countries	464	651	2,307	2,636	2,137
Other countries:					
Netherlands Indies	26,213	22,372	22,064	23,287	24,665
British India	126[1]	1,669	1,764	2,086	1,984[4]
Totals[5]	26,803	24,692	26,135	28,009	28,786
	Per cent of total				
Latin America	1.7	2.6	8.8	9.4	7.4

* Table prepared by U. S. Tariff Commission.

[1] Exports.
[2] Includes cascarilla.
[3] Not available.
[4] Estimated.
[5] Total of above producing countries only.

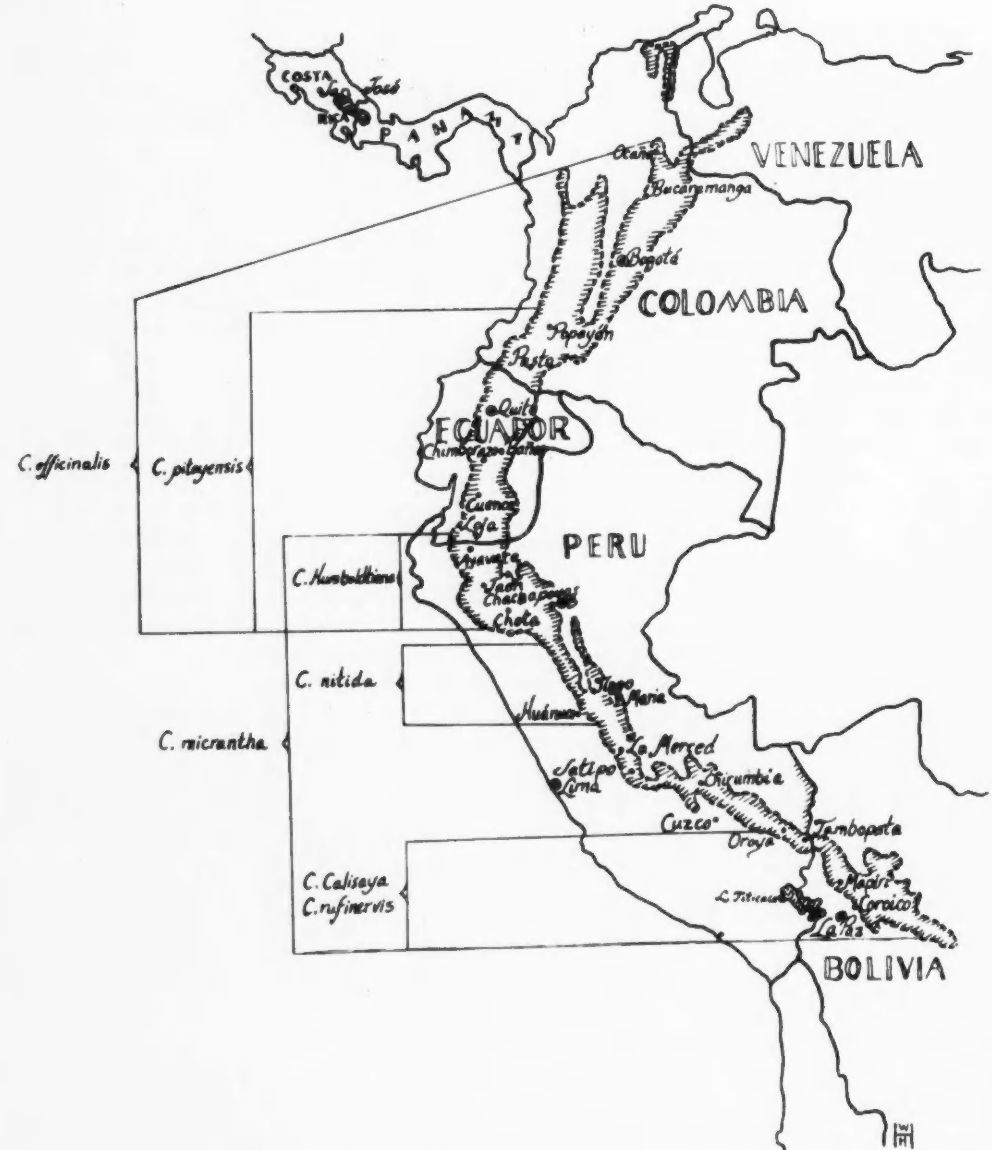


FIG. 1. Map showing distribution of the important commercial species of cinchona in the Andes. Brackets at the left indicate the individual ranges of each species, while the cross-hatched area indicates the over-all range of the genus (*Cinchona amazonica* excluded). Important cinchona-bark centers are located within the cross-hatched area. *C. pubescens* grows throughout the range of the genus but was exploited only in Colombia, Ecuador and northern Peru.

of diplomacy there was some delay in negotiations and exploration, and procurement men were not sent to Latin America until the fall of 1942. Colombia was the first of the Andean republics to ratify an agreement, and so procurement work began in that country. In Table I it is noted that up to the turn of this century Colombia had been the chief Latin America source; it continued to be

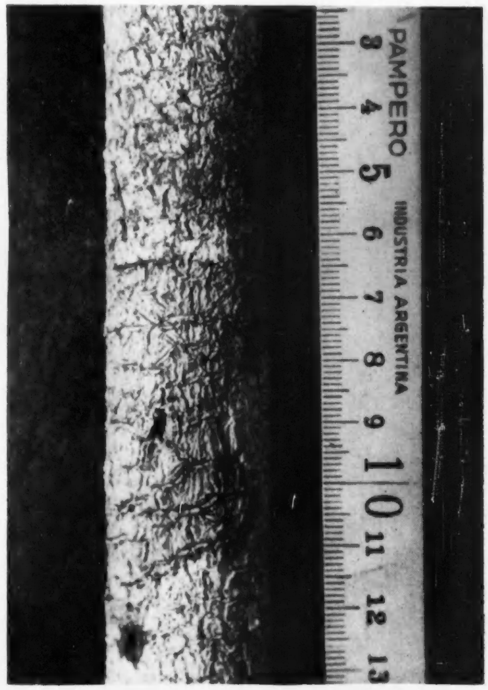


FIG. 2 (*Upper left*). Branches of *Cinchona officinalis* (loja), showing characteristic capsulate fruits. Province of Ayavaca, Peru.

FIG. 3 (*Upper right*). Quill of dry bark of *Cinchona officinalis* (loja) from Penachí in northern Peru. Note cross-fissures.

FIG. 4 (*Lower left*). Leaves and flowers of *Cinchona nitida* from the Cordillera Azul in central Peru.

FIG. 5 (*Lower right*). Characteristic bark of *Cinchona nitida* from the same locality.

the chief producer during the past war period as well, due in no small measure to the fact that its program got off to an early start. Soon cinchona missions were established in Peru and Ecuador, but Bolivia, the source of the rich calisaya barks, never ratified an official cinchona agreement, due to a delicate diplomatic situation. Nevertheless, the Board of Economic Warfare established agents in La Paz to arrange for purchases of surplus quinine and quinine bark. Besides the agreements with those countries in which cinchona trees are native, agreements were made also with Costa Rica and Guatemala where cinchona plantation programs were being initiated. A survey was also started by the American Quinine Company to investigate the cinchona resources of Venezuela, but this was discontinued when the types found proved to be non-commercial.

Procurement

Inasmuch as the primary job of the Cinchona Missions was to search out exploitable stands of commercial cinchona trees, survey parties were organized early. At the start, at least, these groups were made up of a botanist and forester working coöperatively plus such local Latin assistants as were found to be necessary for training purposes in the field. For over two years (1942–1945) these teams of men traversed in their survey work practically all of the principal known cinchona regions of the Andes, finding in addition a number of new previously unknown bark areas.

The task of the botanist was the identification and collection of cinchonas as well as related rubiaceous genera which might prove valuable, especially in a breeding program. In Colombia and in Ecuador where the Missions were staffed with a sizeable number of professional botanists, extensive general collections of plants were also made which will add much valuable information to the flora of those countries. The job of the forester was primarily procurement and involved estimates of bark volume, best harvesting procedure and the like. The survey groups also prepared detailed reports, including geographical data (localities, climate, elevations, *etc.*) of the cinchona areas, a summary of the types of cinchonas available, a list of suggested areas where plantation development would be desirable and feasible and other commercial information valuable in the immediate problem of harvesting and transportation.

Probably the most important permanent contribution resulting from wartime surveys was the collection of plant specimens representing the principal cinchona species. The opportunity for botanists to collect in nearly all the known cinchona zones of the Andes was unique and resulted in the most complete series of herbarium specimens with field observations ever to be made of this difficult genus. The plant specimens collected included not only standard herbarium material but also associated bark and often wood samples. Data regarding bark analyses have been kept with the specimen data so that the commercial value of any species may be known immediately in the future merely through a routine examination of one of these herbarium specimens. Small collections of seed from important species were also made, and these were forwarded to various Latin American centers for use in breeding work.

Besides the bark samples taken from individual trees from which herbarium material have been collected, samples were often taken to represent the bark of a single species in a given area. There was no method to guide the selection of this type of bark sample, for actually little was known concerning alkaloidal distribution in wild cinchona trees. Thus the first survey bark samples were often composed solely of trunk bark separ-

ated by regions and by species, each sample consisting of several dozen pieces of bark (about five pounds) taken from the same number of cinchona trees, more or less evenly distributed throughout an area. Care was observed to dry the samples quickly, not exposing them to rain.

An analysis of the many bark samples collected by the survey groups was the only means of learning whether a given species, variety or form of cinchona was commercially exploitable or not. How necessary it was to have prompt analyses can be seen when it is understood that one type of cinchona may be exploitable in one region and yet in another area, perhaps even a short distance away, the same type may be worthless. So a most important appendage of each Cinchona Mission was the United States Government Cinchona Laboratory whose duty was to analyze not only the bark samples originating from the survey parties but also the many commercial samples which began to come in after harvesting activity had started. Reputable laboratories of this type were located in Bogotá, Quito, Lima and La Paz, and these obviated the long wait previously required between purchases and deliveries when samples were analyzed in the United States or Europe. Prompt analyses also enabled procurement men to check the production continually in all areas, to control adulteration of shipments with worthless barks and to determine the price to be paid for each lot.

The refined methods used in timber cruising in temperate regions could not be followed for bark-estimate cruising in the Andean forests because the extreme ruggedness of the terrain prevented the systematic location of cruise lines; furthermore, the dense cover of vegetation would have made progress very slow. Therefore, cruises, in Peru at least, were conducted along those mule trails and foot trails which pass through the cinchona forests. Data were collected on special form sheets, cinchona trees being tallied by size-class, and species on the lower side of the trail in an eight-meter strip. One hectare was equivalent to 1250 meters of this eight-meter strip. The tally of cinchona trees was converted to pounds of dry bark, using Table III. The average volume per hectare was then applied to the net area of cinchona forests to obtain the total bark volume estimate. The net area of cinchona forest was determined from available maps as altered by field observation.

TABLE III

POUNDS OF DRY BARK BY DIAMETER CLASS

DBH in inches	Pounds of dry bark
2	1
4	6
6	12
8	25
10	45
12	72
14	104
16	133
18	160
20	186
22	208
24	232
26	255

The foregoing table, compiled from measurements taken for various commercial species of cinchona obtained from all site conditions, was used in Peru to obtain bark volumes. It was recognized that a difference existed between bark volumes of the different species, but it was impossible to collect sufficient data from which to prepare an accurate volume table for each commercial species.

Several admittedly cursory though valuable studies were made by survey groups to determine some of the unknown factors which influenced the alkaloidal content of the bark of wild cinchonas. This was found necessary in several cases in order to advise producers on better harvesting methods. For ex-

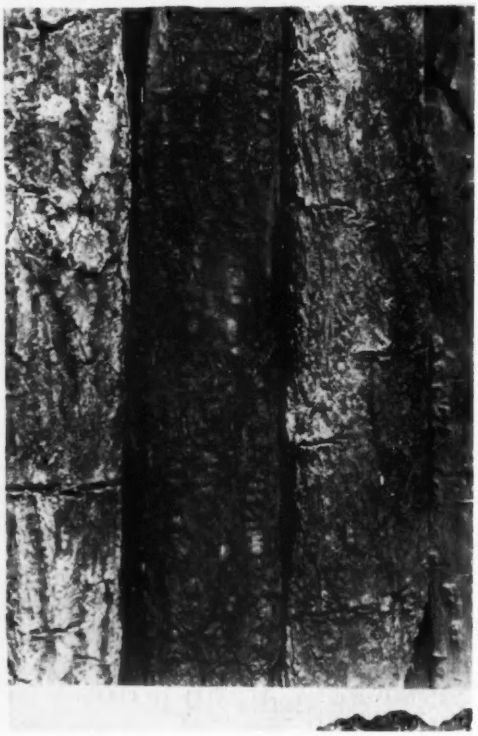


FIG. 6 (*Upper left*). Characteristic appearance of old bark of *Cinchona Calisaya* from the Tambopata Valley.

FIG. 7 (*Upper right*). Leaves and capsulate fruits of *Cinchona Calisaya* in the Tambopata Valley of Peru.

FIG. 8 (*Lower left*). Leaves and stipules of *Cinchona rufinervis* from the upper Inambari Valley of Peru.

FIG. 9 (*Lower right*). Young bark of *Cinchona rufinervis*. The corky layer has fallen off the right hand piece.

ample, in Tabaconas in northern Peru the original survey samples showed better alkaloid content than commercial lot samples obtained later. To assist these producers to get out better bark, it was necessary to make a study of the alkaloidal distribution in individual trees as well as to study alkaloidal variations between trees of different size-classes. In this particular instance it was found that limb bark contains a lower alkaloidal content than trunk bark, and since the survey samples included only bark of the trunk, they had a higher alkaloidal content than the commercial sample. This discovery decidedly improved sampling technique. Continued careful analyses of the commercial species of wild cinchonas brought out the interesting physiological fact that, although the great majority of species have a higher concentration of alkaloids in their trunk bark, a concentration which diminishes towards the branches, one or two species, including important *C. micrantha*, have their highest concentration of alkaloids in their limb bark. Thus harvesting procedure had to vary with the species involved if maximum and most profitable utilization was to be effected. The writer has published elsewhere[3] the results of field sampling experiments which indicate that the concentration of specific alkaloids as well as total alkaloids vary with the size or age of trees, variation depending upon species involved. Mention should also be made, among special studies of the Cinchona Missions, of a program of microscopic investigations of cinchona barks initiated by the Colombia Mission, a program which aided in the identification of commercial barks.

TABLE IV

VERTICAL RANGE OF COMMERCIAL CINCHONA SPECIES IN THE ANDES

Species and (type)	Source	Altitudinal range in feet
C. Calisaya	So. Peru	3500–5000
C. Humboldtiana (negra)	No. Peru	8000–9500
C. micrantha	Peru	1000–5000
C. nitida	Central Peru	5000–6000
C. officinalis (Baños)	Ecuador	
C. officinalis (costrona fina)	Ecuador	7000–8500
C. officinalis (hoja de lucma)	Ecuador	
C. officinalis (loja)	No. Peru	8000–9500
C. officinalis ? (punta de lanza)	So. Peru	4000–5000
C. officinalis (Uritusinga)	Ecuador	7000–9000
C. pitayensis	Colombia & Ecuador	8500–10,500
C. pubescens (bofuda)	Ecuador	5000–8000
C. pubescens (colorada)	No. Peru	6000–9500
C. pubescens (roja)	Ecuador	2500–4000
C. pubescens (rosada)	Ecuador	4000–8000
C. pubescens (serrana)	Ecuador	8500–10,000
C. rufinervis (morada)	So. Peru	5000–6000
C. rufinervis (zamba morada)	So. Peru	3000–4000

Synopsis of Commercial Andean Cinchonas

Like all other plants, species of the genus *Cinchona* require certain environmental conditions for their best development. Thus the genus seems to prefer

[3] Alkaloid distribution in the bark of some Peruvian cinchonas. Carib. For. 7: 79–86. 1946.

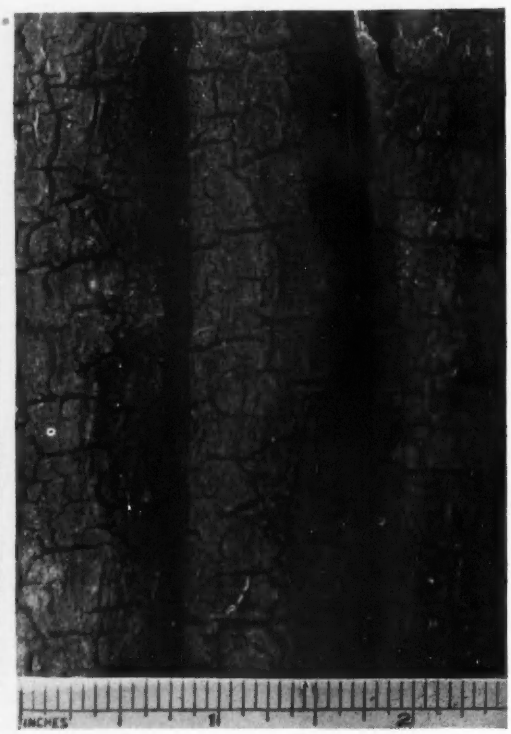


FIG. 10 (*Upper left*). Young shoots (sprouts) of *Cinchona pubescens* (colorada) from Pomocochas in northern Peru.

FIG. 11 (*Upper right*). Characteristic bark of *Cinchona pubescens* (colorada) in the same locality.

FIG. 12 (*Lower left*). A worthless type of *Cinchona pubescens* (*C. obovata* R. & P.), showing typical cinchona flowers. Carpish Pass, Central Peru.

FIG. 13 (*Lower right*). Bark of *Cinchona Humboldtiana?* from Chota in northern Peru, showing characteristic cross-fissuring of this rich quinine bark.

precipitous, well-drained mountain slopes whose climate can best be called subtropical to temperate rather than tropical; and needs a heavy rainfall, generally over 85 inches annually and preferably evenly-distributed throughout the year. Such an environment in a mountainous region generally results in a special type of broad-leafed, evergreen forest called a "mountain rainforest". The rainforests of the higher ridges of the mountains near timberline are often dwarfed and dense, and this variation of the rainforest is known as "mossy-forest", "fog-forest", or "cloud-forest". In South America mountain rainforests or mossy forests cover most of the eastern slopes of the Andean ranges from their junction with the Amazon Basin and its lowland rainforests up to tree-line near 11,000 feet. In addition—in the northern Andes of Venezula, Colombia and Ecuador—mountain rainforests are found on the western slopes of the Andes as well, but fail to enter Peru, except for isolated spots in the north, and Bolivia where the western slopes consist largely of barren desert. In this continuous formation of rainforests one can expect to find representative species of the genus *Cinchona* (see Table IV).

Within their range cinchonas vary from large forest trees to small shrubs. *Colorada* from northern Peru and *roja*

TABLE V

AVERAGE ALKALOID CONTENTS (% DRY WEIGHT) OF NATIVE ANDEAN CINCHONA BARKS (COMMERCIALLY IMPORTANT TYPES)

Species and (type)	Source	Number of Samples	Individual alkaloids present				Total Cryst. Alkaloids
			Cinchonine	Cinchonidine	Quinine	Quinidine	
C. Calisaya	So. Peru	22	0.26	0.86	3.38	*	4.50
C. Calisaya	Bolivia	52	0.55	0.83	3.35	0.07	4.80†
C. Humboldtiana (negra)	No. Peru	3	....	0.89	3.90	*	4.79
C. micrantha (huánuco)	No. Peru	41	4.08	0.05	....	....	4.13
C. micrantha (huánuco)	Centr. Peru	195	3.10	0.03	....	....	3.13
C. micrantha (monopol)	So. Peru	21	2.34	1.06	....	....	3.40
C. nitida	Centr. Peru	3	1.02	1.65	0.43	0.10	3.20
C. officinalis (Baños)	Ecuador	42	1.36	1.69	0.91	Trace	3.96†
C. officinalis (costrona fina)	Ecuador	32	0.12	1.06	1.58	....	2.76†
C. officinalis (hoja de lucma)	Ecuador	78	1.16	1.12	0.41	....	2.69†
C. officinalis (Uritusinga)	Ecuador	10	0.31	0.67	1.42	....	2.40†
C. officinalis (loja)	No. Peru	15	0.88	2.48	0.10	Trace	3.46
C. officinalis? (punta de lanza)	So. Peru	8	1.71	1.16	0.08	0.07	3.03
C. pitayensis	Ecuador	92	2.63	0.55	1.68	0.19	5.05†
C. pubescens (bofuda)	Ecuador	36	2.12	....	....	....	2.12†
C. pubescens (rosada)	Ecuador	165	2.72	....	....	....	2.72†
C. pubescens (serrada)	Ecuador	60	3.30	....	....	....	3.30†
C. pubescens (roja)	Ecuador	31	1.96	1.57	1.48	....	5.01†
C. pubescens (colorada)	No. Peru	44	1.42	0.11	....	....	1.53
C. rufinervis (morada or zamba morada)	So. Peru	29	1.11	1.63	2.02	*	4.76

* No analysis made for quinidine.

† Data from Martin, W. E. & Gandara, J. A.: Alkaloid Content of Ecuadoran and other American Cinchona Barks. Bot. Gaz. **107**: 184–199. 1945.

FIG. 14 (*Upper left*). Leaves of *Cinchona micrantha* (huánuco) shown against a characteristic section of the bark of the trunk of an old tree of this species at Tingo María, Peru.

FIG. 15 (*Upper right*). Typical *Cinchona micrantha* forest near Tingo María, Peru. Leaves of trees of this species may be seen in the leftmiddle foreground of the picture.

FIG. 16 (*Lower left*). Leaves of *Cinchona micrantha* (monopol) from the upper Inambari Valley of southern Peru.

FIG. 17 (*Lower right*). Selected bark samples taken from a single tree of *Cinchona micrantha* (huánuco) in northern Peru, showing the wide range of variation in the general bark aspect. Bark at the upper portion is from the base of the trunk, while the small quills at the lower right are from young branches and are relatively richer in alkaloids in this species.

of Ecuador (both forms of *C. pubescens*) are often the dominant trees of the rain-forests in which they occur. *Colorada* often attains a diameter of three feet and a height of 100 feet. In general, the less precipitous the slopes the larger the size of cinchona that can be expected, and those types which delight in growing on precipices where conditions of growth are poor are generally small trees. On the other hand, the shrub-like types are nearly always inhabitants of grassy or brushy slopes called "pajonales".

Of the too-numerous species, varieties, forms and hybrids of *Cinchona* which exist in the Andean forests, only a relatively few became important in the harvesting activities initiated by the wartime procurement program. The important species are *C. Calisaya* Weddell, *C. Humboldtiana* Lambert, *C. micrantha* Ruiz & Pavon, *C. nitida* Ruiz & Pavon, *C. officinalis* L. sensu lat., *C. pitayensis* Weddell, *C. pubescens* Vahl sensu lat., *C. rufinervis* Weddell, and *Remijia pedunculata* Weddell. A brief synopsis of each of these recently important species follows.

Cinchona Calisaya Weddell: This species is limited to moderate elevations of southern Peru and Bolivia, extending from the Peruvian Province of Sandia (included in the province of Carabaya in the last century)—where it occurs in the mountains from which arise the headwaters of the Inambari and Tambopata Rivers—into the neighboring Provinces of Caupolicán and Larecaja in the valleys of the Tuichi and Beni Rivers in Bolivia. Actually most wild calisaya bark comes chiefly from southern Peru, for most calisaya bark in Bolivia originates from small plantations in the old wild calisaya region. Rusby records that this was true in the decades concluding the last century, and William Pennock, who made a preliminary wartime survey of cinchona in Bolivia for the U. S. Department of Agriculture, informed the writer that wild calisaya trees are practically non-existent in Bolivia.

C. Calisaya is one of the most valued of all wild cinchona barks, falling as it does among the quinine-yielding species. It is generally conceded that from an especially high-yielding strain of this species, *C. Ledgereana* Moens ex Trimen has been developed. Calisaya bark is usually characterized by a slatey-gray outer color, a strongly-marked, lateral fissuring or cross-fracture (which makes it readily identifiable) and a tendency to curve laterally when drying. The outer corky layer readily detaches upon drying, leaving bare a hard reddish-purple surface which is usually deeply marked by the imprints of the fissuring.

The best wartime survey samples of wild Calisaya from Peru yielded 7.14% total crystallizable alkaloids, with 7.20% of anhydrous quinine sulfate. Commercial lots of calisaya yielded much lower proportions of quinine and total alkaloids. The lower averages obtained in commercial lots are usually due to poor drying conditions and to adulteration with other barks. Commercial lots of Peruvian calisaya bark are probably always mixed with the bark of *C. rufinervis* discussed below. It will be noted from Table V that, although considered a quinine bark, calisaya also contains small percentages of cinchonidine, cinchonine and quinidine, with proportions usually in that order.

Cinchona Humboldtiana Lambert: The writer is uncertain whether the cinchona described herewith represents Lambert's species originally recorded from the Province of Jaén in northern Peru. Lambert's species is said to have been collected by survey groups in southern Ecuador. Specimens of the cinchona which the writer has in mind have been collected in Peru only in the Province of Chota (Cajamarca) where small-statured trees of this species, known as "negra", grow in scattered mossy-forest at elevations of 8,500–9,500 feet.

Like calisaya, negra bark is easily recognized by a conspicuous lateral fissuring of its outer corky layer which, however, is rich-brown in color and not gray like calisaya. The bark is thin, clean-fracturing, with an inner fibrous layer considerably thicker than the outer corky layer; the outside layer shows no tendency to shed when dry. This species appears to be one of the richest of the wild quinine barks, averaging 3.67% T.C.A. with 3.27% anhydrous quinine in commercial lots. However, selected survey samples have yielded 5.82 T.C.A. with 4.66 quinine sulfate (see Table VI). Only small quantities of bark of this species were exploited in Peru. It should have value as a high-yielding, cold-resistant type for introduction into a breeding program.

TABLE VI

Alkaloid Content (% Dry Weight) of Commercial Peruvian Cinchona Barks (Selected Individual Analyses of Wild Trees)

Species and (type)	Source	Individual alkaloids present				Total Crystallizable Alkaloids
		Cinchonine	Cinchonidine	Quinine	Quinidine	
C. Calisaya	So. Peru	Trace	0.81	5.34	*	6.15
C. Humboldtiana (negra)	No. Peru	....	1.16	4.66	....	5.82
C. micrantha (huánuco)	No. Peru	6.02	Trace	....	....	6.02
C. micrantha (huánuco)	Centr. Peru	4.92	0.28	....	....	5.28
C. micrantha (monopol)	So. Peru	3.94	1.05	....	....	4.99
C. nitida	Centr. Peru	1.07	2.40	....	....	3.47
C. officinalis (loja)	No. Peru	1.30	3.30	0.20	....	4.80
C. officinalis (punta de lanza)	So. Peru	1.95	1.85	....	*	3.80
C. pubescens (colorada)	No. Peru	1.43	1.74	....	....	3.17
C. rufinervis (morada or zamba morada)	So. Peru	2.30	1.37	1.78	*	5.45

* No analysis made for quinidine.

Cinchona micrantha Ruiz & Pavon: *C. micrantha* grows at relatively low elevations compared with other commercial species of cinchona (*C. pubescens* (roja) excepted). In Peru, its center of distribution, it has been found at elevations of 1,000 feet in the Huallaga Valley at Uchiza and on the Pampas de Sacramento near Aguaytia, and at less than 1,000 feet in the Cosñipata Valley in the Department of Cuzco, but it seldom occurs any higher than 5,000 feet. It is always found within the limits of mountain rainforests and never migrates into the upper zone of mossy forests. Although primarily a forest-loving species which can attain a large size, it also acts as a weed type seeding in on roadcuts, cliffs, abandoned clearings and the like. Generally found on slopes, it nevertheless will tolerate flat land, for large trees are common on the bottomlands of the Huallaga River Valley near Tingo María. The species ranges from southern Ecuador throughout Peru into Bolivia.

C. micrantha is historically interesting as being the source of the "gray" or "huánuco" barks of central Peru which were for a long time a prime source of alkaloids in the cinchona boom of the early part of the last century. Its lack of quinine caused its demise as a commercially important species. Unim-

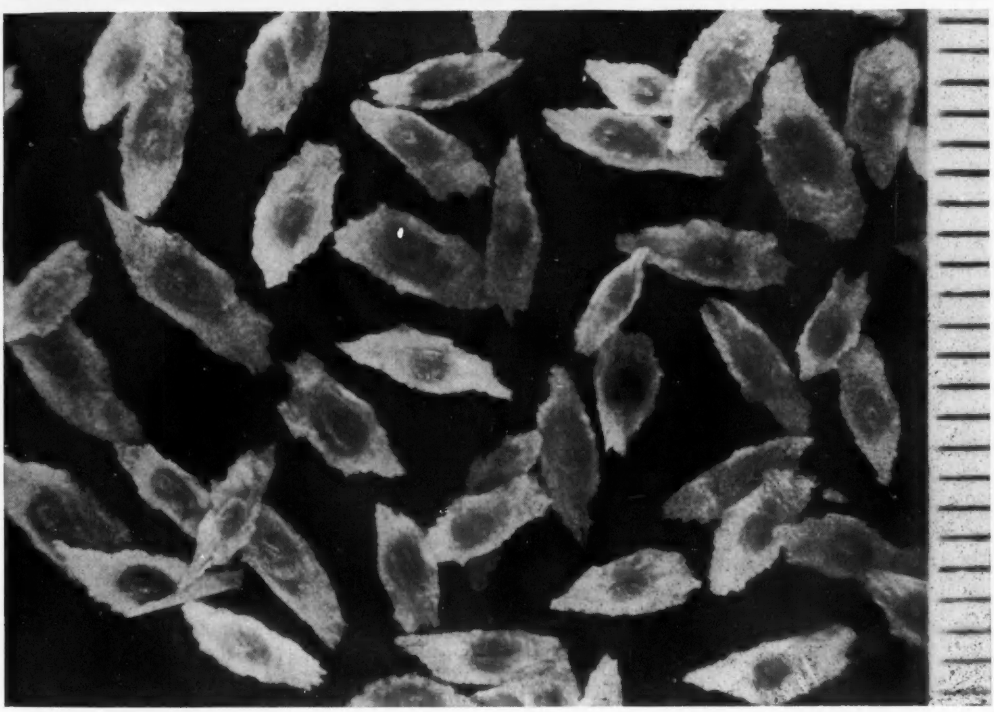


FIG. 18 (*Upper*). Flowering branches of *Ladenbergia magnifolia* from southern Peru. The worthless bark of this tree was one of the most common adulterants of cinchona bark during the war.

FIG. 19 (*Lower*). Seeds of *C. pubescens* (colorada). Scale in mm. The seeds of other species differ in absolute and relative lengths and widths, and in the width and fringing of the wings.

portant in normal times, the bark is important in times of quinine shortages because it can be used in the production of totaquine. Thus *C. micrantha* was the most important non-quinine species in Peru, and its exploitation contributed more to the over-all tonnage of bark produced in Peru during the 1943–1945 period than that of any other commercial cinchona.

Two principal varieties, each with a definite geographical distribution, can be recognized in this species. Bark of *C. micrantha* is called "huánuco" in northern and central Peru; "monopol" in southern Peru. Huánuco is a cinchonine bark and seldom contains any other crystallizable alkaloids (when another alkaloid is present it is cinchonidine); it averaged 3.17% T.C.A., but in the northern sections of Peru it has analyzed as high as 6% T.C.A. Monopol bark can likewise be classified as a cinchonine bark, but a considerable amount of cinchonidine is always present, and the latter alkaloid amounts to about one-third of the T.C.A. which averaged 3.40% for the wartime period. The highest T.C.A. reported for monopol was 4.50%. The alkaloidal differences are also distributed geographically and thus fit in nicely with the bark and other botanical differences in upholding the segregation of geographical variations in this species.

Huánuco and monopol bark differ in several respects: huánuco tends to shed its outer cork layer when dry, to have a strong lateral curvature and to possess at times suggestions of cross fissuring; monopol, on the other hand, never sheds its outer cork layer when dry, tends to have a longitudinal curvature when dry and never possesses cross-fissuring. Quills of huánuco bark from young trees, originating from northern Peru (where the tree is sometimes locally interplanted with sugarcane) tend to be slatey-gray in color and possess characteristic, irregular, longitudinal ridges when dry. Young bark of huánuco or monopol from other parts of Peru lack this morphological feature. In general, the surface of mature bark of *C. micrantha* is yellow-brown to gray-brown, and is often spotted with irregular warts or ridges.

Cinchona nitida Ruiz & Pavon: Trees of this species inhabit exposed ridge forests of the Huallaga drainage system in the Department of Huánuco, Peru, and there is a record of it collected in the Loja zone by the Ecuador survey groups. The latter record should be closely checked, since the species is not known in intervening yet explored northern Peru.

The light-brown bark of *C. nitida* possesses a warty cork layer and lacks a cross fracture, thus resembling superficially not the *C. officinalis* but rather the *C. pubescens* group of cinchonas. *C. nitida* is a cinchonidine bark with substantial proportions of cinchonine. Although survey samples of this bark averaged 3.47% T.C.A., the species was not known to have been exploited during the war period, though it was one of the prominent "gray" barks harvested in the 19th century.

Cinchona officinalis L.: This species ranges from Colombia into northern Peru usually at higher elevations where the terrain is rough and covered often by dense low-statured mossy-forest. Innumerable forms exist, but apparently the greatest variety inhabits the southern portion of Ecuador in the vicinity of Loja where the quinine-yielding Uritusinga variety, the type of *C. officinalis*, became the species earliest exploited in commercial cinchona history.

Because this complex includes so many variants it is impossible to give any all-inclusive description of the bark, which however is usually gray and laterally-fissured. With few exceptions the many varieties of *C. officinalis* proved commercially exploitable during the war, being especially valuable in Colombia and in

FIG. 20 (*Upper left*). Cutting down a large tree of *Cinchona micrantha* (huánuco) near Tingo María, Peru.

FIG. 21 (*Upper right*). A cascarillero stripping bark from a felled tree of *Cinchona pubescens* (colorada) in northern Peru.

FIG. 22 (*Lower left*). A cascarillero stripping bark from *Cinchona micrantha* (huánuco) in central Peru.

FIG. 23 (*Lower right*). Cascarilleros drying cinchona bark on a cleared portion of a river bank in southern Peru.

Ecuador where the species (see Table V) could be classified, depending upon the type as either a quinine, cinchonine or cinchonidine bark.

Cinchona pitayensis Weddell: Probably more general information was compiled about this important species as a result of the war surveys than of any other commercial cinchona. Believed in 1942 to be a species restricted to southern Colombia and originally described from forests near Pitayo on the slopes of the Nevado del Huila, its known distribution was extended by botanists of the Ecuadorian and Peruvian surveys down into the western Andes south of Quito and even farther south into northern and possibly central Peru. In northern Peru this species has been passing under another and earlier binomial, *C. macrocalyx* D.C., which probably will have to replace the well-known name *C. pitayensis*.

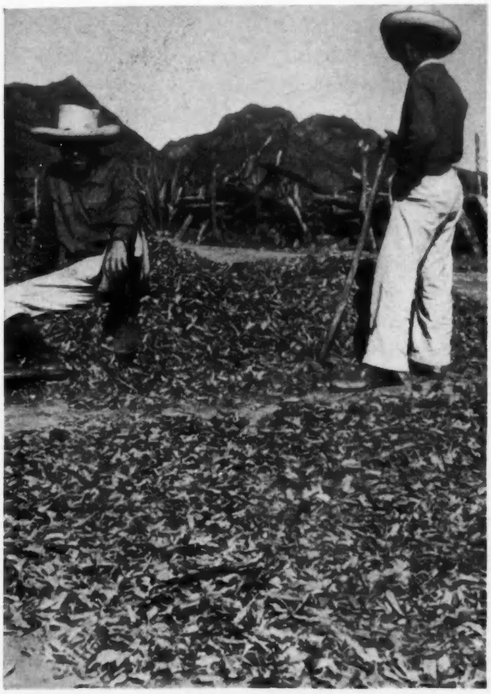
This species inhabits steep slopes at high elevations reaching right up to the Andean treeline bordering upon the paramos or jalca. In Colombia and Ecuador *C. pitayensis* is found in regions of very heavy rainfall, but in northern Peru the sites it occupies often pass through a prolonged dry season. Steere[4] has given us a detailed report of the species as it occurs in Ecuador, and he points out that in the northern half of its range trees are most abundant on rich volcanic soils where they may grow to a large size, as much as three feet in diameter. In Ecuador *C. pitayensis* begins to diminish in size, and in its southernmost extent in Peru the species is definitely a small tree.

Pitayo bark is thick and heavy, dull-brown to gray, but is so frequently overlain with closely-appressed lichens as to appear mottled-whitish. The dry bark has a strong lateral curvature, and the outer surface is marked with transverse fissures, a characteristic of all the commercially important quinine barks. *C. pitayensis* is the most important quinine species in the northern Andes. Indeed in Colombia commercial lots of the bark average higher in T.C.A. (6%) than any wild cinchona anywhere in the Andes, and the same bark regularly yields 3% quinine sulfate. The alkaloidal yields from this species diminish with its southern extension, the T.C.A. content averaging about 5% in Ecuador and less than 3% in northern Peru, where no volcanoes exist and the soils are correspondingly poorer. The reduction in alkaloid content parallels the gradual change of the species from a type in which quinine is the dominating alkaloid in Colombia and northern Ecuador to a cinchonine-dominated type in central Ecuador. Since this species also possesses quinidine and cinchonidine, it is seen that it runs the whole gamut of major alkaloids.

Cinchona pubescens Vahl: This is the most widespread and probably the most variable of all species of cinchona, ranging in one or more forms latitudinally from Costa Rica to Bolivia (see map), and altitudinally from treeline around 11,000 feet down to 3,000 feet (in the coastal Colonche Hills of Ecuador); most forms occur, however, between 4,000 and 7,500 feet. For the most part individuals of this species are small- to medium-sized trees which are sun-loving, inhabiting open second-growth woodlands or forest borders, or clearings as a weed tree. On occasion certain forms of *C. pubescens*, for instance, colorada of northern Peru, are dominant trees of the forest in which they occur, and in such sites individuals may attain a diameter of over three feet and a height of over 100 feet.

As might be expected in so variable a species group, the synonymy of *C. pubescens* and its forms is very complex. Vari-

[4] Steere, W. C.: The discovery and distribution of *Cinchona pitayensis* in Ecuador. Bull. Torr. Bot. Club 72: 464–471. 1945.



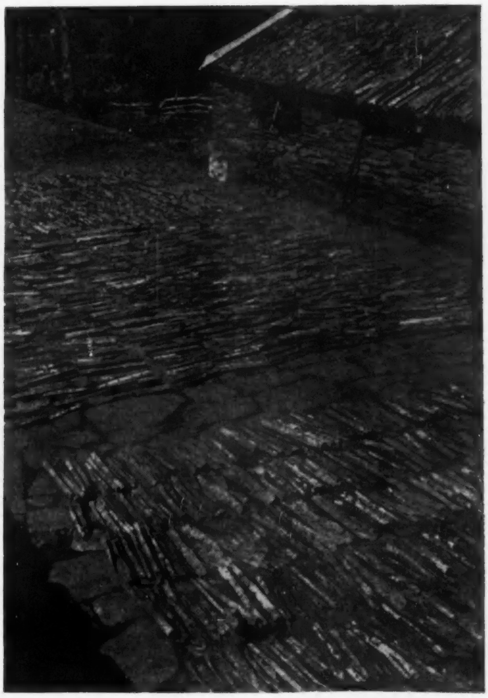


FIG. 24 (*Upper left*). Bark of *Cinchona officinalis* (loja) being sun dried in chip form. Penachí, Peru.

FIG. 25 (*Upper right*). Cinchona bark drying in strips in southern Peru.

FIG. 26 (*Lower left*). Making up fifty-pound packs of calisaya bark in the forests of the Tambopata Valley. In this form the dry bark is carried by Indians to the roadhead.

FIG. 27 (*Lower right*). *Cinchona officinalis* (loja) bark arriving in the bark center of Huancabamba in northern Peru.

ation is carried over into the morphological aspects of the bark of the forms of *C. pubescens*. Bark of the weedy types, the small or medium-sized forms, is rather thin, relatively smooth though occasionally warty, yellowish-brown and with no shedding of the cork layers when dry. Such barks are exceedingly resinous, making alkaloidal extraction difficult, yet they have seldom yielded more than traces of crystallizable alkaloids and so are generally without commercial value. Exploitable barks are obtained from the larger growing types, and these supply bark which is thick and heavy, often yellowish or reddish in color and with an outer thick corky layer which may shed in flakes when dry. In no case does one find the conspicuous cross-fissures so characteristic of the important commercial quinine barks. The few commercial forms of *C. pubescens* appear to be all cinchonine barks, and in certain of these —such as the "bofuda", "rosada", and "serrana" varieties of Ecuador—cinchonine, averaging 2–3%, is the only alkaloid present. In other commercial forms cinchonine remains dominant, but other alkaloids, such as cinchonidine (in colorada of Peru) or both cinchonidine and quinine (in roja of Ecuador), are also present. In Ecuador *C. pubescens* has developed its more valuable commercial forms, one of which, vigorous growing roja (sometimes called *C. succirubra*) has been cultivated in that country for years and was collected by Spruce about 1860 to form the basis of extensive plantations in British India. An old abandoned planting of this form in Guatemala was important as an early wartime source of bark in 1943, and the same form is becoming increasingly valuable in modern breeding work in cinchona.

Cinchona rufinervis Weddell: The range of *C. rufinervis*, called "morada" or "zamba morada" in Peru because of the solid purplish coloring so often present in the lower surfaces of the leaves, parallels that of *C. Calisaya;* and its altitudinal distribution is much the same, from 3,000 to 6,000 feet, in the province of Sandia in southern Peru and the neighboring provinces of northern Bolivia. It is nearly always found on steep declivities where soil is shallow, and for this reason it is usually a fairly small tree. Bark of morada closely resembles calisaya bark in its pale-grayish outer color, its cross-fissures and in the tendency of the fragile corky layers to fall off of dried bark. Like calisaya, *C. rufinervis* is a quinine-yielding species, but, unlike calisaya, morada has substantial proportions of cinchonidine and cinchonine. During the recent war years the quantity of morada bark exploited in Peru, though small, was probably greater than the quantity of wild calisaya. Producers usually mixed the two types, calling the result "calisaya bark", but because of their close physical appearance it was impossible to detect such, in this case, harmless mixture of two valuable barks. Such adulteration may have been carried on in the morada region of Bolivia as well.

Remijia pedunculata Weddell: Although certain species of *Ladenbergia* are known to possess cinchona alkaloids, *Remijia* is the only non-cinchona which has proved commercially exploitable through the years. *R. pedunculata,* a Colombian species, ranges along the lower eastern slopes of the Cordillera Oriental from Villavicencio to the Ecuadorean frontier and occurs also in the drainage system of the Magdalena River. Only in the Bucaramanga area did the bark prove sufficiently rich (averaging 3% quinine sulfate) for large scale exploitation. In general, stands located at 3,000 feet and above proved valuable, but at lower elevations the bark was worthless.

Fosberg describes the bark as "entirely different from cinchona . . . reddish

brown in color with a thin papery outer layer that peels off very readily, leaving a hard brown outer surface irregularly marked with very shallow transverse channels of a darker color". The cupreine content of the bark makes it chemically distinguishable from cinchona barks. Small lots of Remijia bark from unknown species were also shipped from Iquitos in Peru.

Commercial Development

The actual work of harvesting, drying, transporting, storing and embarking cinchona barks in the several Andean countries was contracted out to agents, each of whom was assigned a given area for development. Agents were usually well established local business men whose experience often had been in the procurement of botanicals of one sort or another. Survey personnel or production men of the Cinchona Missions worked closely with the agents, checking all phases of their activity in the harvesting program, giving the agents advice and making recommendations to their own office. When new cinchona stands were discovered and proven of exploitable quality as a result of survey work, the general agent for the area was notified. He in turn generally attempted to initiate and stimulate a program of production, making advances to local men who would act as producers in the area in question. At the same time the agent would set up buyers to represent him in purchasing the cascarilla at interior points. The problem of ownership of cinchona stands did not crop up, for in most of the countries all cinchona trees wherever located, on public or private land, were declared national property under the cinchona agreement and open to exploitation to all.

The actual job of harvesting fell on the "cascarillero" or "quinero", as the cinchona bark cutter is called. Actually there were very few real cascarilleros remaining in the Andean area. They had died out a generation or so back with the death of the old industry in South America, and it was common practice of cinchona botanists to teach prospective cascarilleros which of the trees growing in their forests were cinchona trees.

Labor was one of the two big problems in procurement. Population centers were usually distant from cinchona forests, thus requiring workers to break away from home for such periods as might be necessary to harvest barks and to live under conditions most primitive as to housing and food. This would have been feasible if the forest were a familiar spot, but unfortunately to many it was a strange place, a place to be feared, and the opportunity to earn money did little to cure this natural fear. Thus labor turnover among cascarilleros was often great. Some of the field surveys even had to enforce labor to get the men required for certain distant trips.

Universal harvesting tool of the cascarillero is the machete, though an ax is often needed to fell the tree. Cascarilleros sometimes girdle cinchona trees several months before felling, claiming that this procedure increases the yield of alkaloids in trunk bark; experiments might make fruitful checks on these claims. Once felled the bark is simply cut off from the trunk and from the larger branches, depending upon the size and the species of cinchona involved. Root bark is ignored. The inner bark surface is light-colored as it comes from the tree, but in the air and light it very rapidly turns to a rust color whose intensity in a general way varies with the relative concentration of alkaloids, the darker the color the higher the concentration. For convenience in handling in the drying process as well as in baling and transportation, cinchona bark is usually cut off in long strips of the size (one to two feet long) convenient to the individual worker. Such strips from

young trees or branches of older ones are often thin and inroll during drying, forming the familiar quills of bark. Heavy marginal barks (*e.g.*, barks like colorada whose alkaloidal content was close to the minimum acceptable for purchase under the Cinchona Agreement) or barks difficult to peel (often a seasonal difficulty) were often cut off as chips or fragments which dried faster than larger strips and thus tended to conserve alkaloids. Wasteful practices, often difficult to control, crept in, such as stripping the bark from a standing tree but leaving valuable amounts as a total loss out of reach on the upper trunk and branches.

Most critical procedure in the harvesting of wild cinchona bark is the problem of drying. In a plantation this problem is non-existent, but in the forest, where facilities for natural or artificial drying are scarce and rains are often heavy and regular, proper drying is an everpresent problem. In general, it may be said that the faster the drying process the greater the original percentage of crystallizable alkaloids conserved. Badly dried bark is recognizable by the poor color of its inner surface which tends to be grayish rather than rich rusty brown. Easiest and least expensive procedure in drying is to carry the fresh bark to nearby clearings in the forest, often a river bank where air currents and ample sunlight produce natural and effective drying, but only after several weeks time. However, in case of rain the bark must be picked up and placed under shelter or covered—an often impossible task where large quantities are involved. Bark allowed to stand in rain for any lengthy period (a day or more) has a noticeable reduction in T.C.A., perhaps through leaching, and controlled experiments effected in the field in Peru have shown this alkaloid loss to vary from 8% to 45%.

The difficulty of drying bark in the cinchona belt resulted in the introduction of drying under shelter in the shade, or of artificial drying by heat. Simple thatched shelters with drying racks were sometimes made by small operators, and these were modified so as to permit the building of a fire beneath to speed drying. Where harvesting operations were on a large scale, drying ovens of varying types were constructed, and certain of these might hold several tons of green bark, effectively drying it in a day or two at a maximum safe temperature of 75° C.

Once dried the bark was essentially in the form that it was to arrive in, in the United States, for it required only sampling (to determine the sales price of the lot), baling and transporting. Transportation was, after labor, the second important problem of wartime cinchona procurement, for most cinchona stands were situated in exceedingly rough mountainous terrain and often distant from arteries of transport. As often as not foot-trails or mule-trails were the only connecting links with the harvesting areas, and in some cases even these were lacking, requiring the expenditure of funds in their construction. In several instances air-strips were constructed to bring out bark which otherwise could not have been harvested.

Fresh cinchona bark loses about 75% of its weight in the drying process, but even when dry it is a bulky product. Had the crude bark been permitted to be ground up before shipment the cost of transportation would have been reduced a hundredfold. Even better would have been what was often suggested by field men but always rejected in Washington —the simple extraction of crude alkaloid in the country of bark origin and the subsequent shipment of the extract for final refinement in the United States. When even the best wild commercial bark averaged only around 5% T.C.A., in other words five pounds of alkaloids per 100 pounds of bark, it can be readily

FIG. 28 (*Upper*). A view in the famous calisaya district of the Tambopata Valley in southern Peru.

FIG. 29 (*Lower*). Seed beds sheltered by thatched roofs from sun and rain at a small plantation in the Inambari Valley in southern Peru.

TABLE VII

ANNUAL SOUTH AMERICAN PRODUCTION OF CINCHONA BARKS IN POUNDS (DRY BARK)

Country	1938*	1943†	1944 (Jan.–March) Period
Bolivia	1,950,000	1,222,411	142,000
Peru	185,000	292,650	377,000
Ecuador	Not available	1,983,574	1,976,000
Colombia	2,000	3,186,414	3,288,000
Totals	2,137,000	6,685,049	5,783,000

* This column covers total production, but other columns cover only exported bark; Bolivia, Peru and Ecuador were manufacturing their own quinine and totaquine during this period.

† Total of bark received in the U.S.A., not counting small losses through enemy action. Figures from Foreign Economic Administration.

seen how much useless material was shipped to this country during the war period.

Wartime Bark Production

Data are not available for the total production of cinchona bark in Latin America during the war years 1942–1945, but Table VII gives a general idea of how the procurement program steadily stimulated production in increasing amounts from the pre-war average typified by the 1938 production. To be taken into account, however, is the fact that the figures for 1938 probably cover only high-grade commercial bark, whereas the bulk of wartime production was made up of marginal bark, in other words, bark commercially unprofitable to exploit in peacetime.

Table VII indicates the production rank of the Andean cinchona countries, though failing to indicate what the bark poundage was equal to in extracted alkaloids. Thus, although Bolivia was the lowest producer in the three-months period in 1944, the alkaloidal yield of her rich quinine bark undoubtedly surpassed the total yield from Peruvian bark in the same period.

Total bark production figures are available for Peru (see Tables VIII and IX), and through projection may give a general idea of production in the other countries, though of course the species exploited varied. It is unfortunate that similar estimates were not made in Colombia and Ecuador. Prior to 1943 the annual Peruvian production averaged about 185,000 pounds, the 1938 total. Table VIII shows not only the production but also the quality of barks produced in Peru, while Table IX is a breakdown of the production of bark and

TABLE VIII

WARTIME PRODUCTION OF CINCHONA BARK IN PERU (IN POUNDS AND QUALITY)*

Year	–2% T.C.A.	2% to 2.99% T.C.A.	3% and over T.C.A.	3% and over Quinine	Totals
1943	2000	13,400	104,600	46,000	166,000
1944	1,070,000	336,000	1,364,000	200,000	2,960,000
1945	....	....	890,000	180,000	1,070,000
Totals	1,072,000	349,400	2,358,600	426,000	4,196,000

* Modified from a table prepared by Earl J. Rogers, formerly Forester, FEA Cinchona Mission, Lima.

alkaloids by species and varieties of cinchona.

As always in any program of exploitation, there existed Latin critics in the Andean republics who felt that the wartime cinchona harvest liquidated the Andean supply of bark. This was far from the truth, for in the first place most really worthwhile wild bark such as calisaya had already been so depleted as to be of little importance. Many of the other barks, under normal circumstances, would be below commercial grade, so as a matter of fact, instead of losing, the Latin countries were enabled to gain and profit on a resource which had value only because of the vicissitudes of a war which kept the Allies from the primary plantation source of quinine. And if the bark utilized could be considered a loss, it should be pointed out that all species of cinchona sprout vigorously, thus restocking an area in a decade or two. The "gray bark" areas of central Peru, which had been supposedly depleted to the danger point in the last century, were found to be so fully restocked that they proved the most important source of bark in that country; and Colombia, where the last great Andean exploitation took place less than a half century ago, turned up again in the World War II years as the Number One Latin American producer with much of her production originating on former exploited areas. Of the 370,000 tons of commercial bark estimated as existent in Peru in 1942, the procurement program utilized by the end of 1945 only about 2,000 tons, or 0.6% of the total. Normal growth replaced the total Peruvian cinchona bark harvest of 1943–45 in less than a year.

TABLE IX

ESTIMATE OF HARVESTED BARK (IN POUNDS) AND EXTRACTED ALKALOIDS (IN POUNDS) AND VALUE ($US) OF COMMERCIAL CINCHONA SPECIES IN PERU (1943–1945)*

Species and type	Pounds of bark	Quinine (anhydrous)	Cinchonidine	Cinchonine	Total cryst. Alkaloids	Value F.O.B. Peru
C. micrantha (huánuco)	1,894,600	......	400	64,000	64,400	$227,352
C. micrantha (monopol)	394,000	......	4,200	9,200	13,400	47,280
C. pubescens (colorada)	1,296,800	......	15,000	194,400	209,400	109,504
C. rufinervis (morada)	200,000	4,000	3,200	2,200	9,400	28,000
C. Calisaya	126,000	4,200	1,000	400	5,600	37,170
C. officinalis (loja)	184,600	200	4,600	1,600	6,400	22,152
C. Humboldtiana (negra)	100,000	4,000	800	......	4,800	31,500
Totals	4,196,000	12,400	29,200	271,800	313,400	502,958

* Modified from a table prepared by Earl J. Rogers, formerly Forester, FEA Cinchona Mission, Lima.

Cinchona Plantation Development Plan

As pointed out in the introductory paragraphs, a concommitant feature of wartime procurement of wild cinchona bark was the establishment, if possible, of plantations of high-yielding cinchona trees in this hemisphere—a plan which, if effective, would insure a protected industry in case of another emergency. The best summary of the revival and present status of the Latin American

FIG. 30 (*Upper*). Fundo Sinchono, a cooperative U.S.-Peruvian cinchona plantation in the Cordillera Azul of central Peru.

FIG. 31 (*Lower*). The two most important cultivated strains of cinchona (*Ledgeriana* on the left and *succirubra* on the right) growing in beds at Fundo Sinchono.

Cinchona Plantation Program has been written by Wilson Popenoe[5] whose account is recommended to those interested and of which what follows is a brief digest with additions.

Actually the strategic need for agricultural experimental work on cinchonas in this hemisphere had been anticipated and initiated a decade before the war by Merck and Co., largest U. S. processors of cinchona bark, who—with the backing of the U. S. Dept. of State and U. S. Dept. of Agriculture, the Dept. of Agriculture of Guatemala, the United Fruit Co. and others—had established seedbeds and experimental plantings of the Far Eastern Ledgeriana stock in Guatemala. Besides being better situated, in comparison to the distant native Andean cinchona regions, Guatemala also possessed fine volcanic soils and at elevations at which commercial species are known to thrive. In addition to Old World stock, many new strains of wild cinchonas were introduced from the Andean countries in the prewar decade. Thus, at the start of World War II, experimental plantings were already established in Guatemala and in Costa Rica; and in addition there existed older plantations, usually very small, of native Calisaya trees in Bolivia and southern Peru, of imported Ledgeriana strains in the Chanchamayo Valley of central Peru, of native huánuco trees in the Jaén Province region of northern Peru,

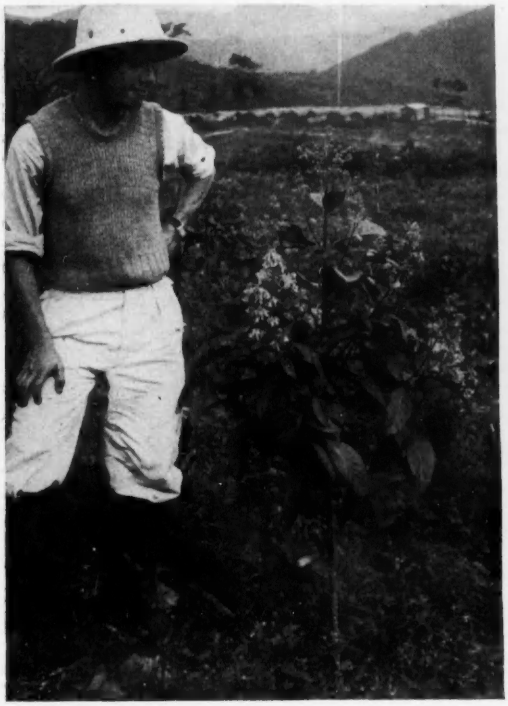


FIG. 32 (*Left*). A young flowering tree of *Cinchona Ledgeriana* growing in the coöperative plantation at Fundo Sinchono, Peru.

FIG. 33 (*Right*). A bud-graft of *Cinchona Ledgeriana* on *Cinchona succirubra* root-stock. The result yields a vigorous-growing disease-resistant root-stock and a high-yielding trunk. *Ladenbergia magnifolia* sometimes is used as a vigorous root-stock.

[5] Popenoe, Wilson: Cinchona, the "Fever Tree". Chapter 6 in "New Crops for the New World". Charles Morrow Wilson, editor. MacMillan Co. 1945.

and of native succirubra trees in the Telimbela area of Ecuador on the western slopes of Chimborazo.

The outbreak of war gave a terrific impetus to plantation activity. Mexico established a cinchona station in southern Chiapas. The work in Guatemala was expanded with the U. S. Government taking control over the El Porvenir plantation which it used first as a source of succirubra bark, exploited from trees of an old abandoned stand planted in the area in the 1880's (from January 1943 to March 1944 El Porvenir supplied 773 tons of bark), and then as a modern cinchona experiment station where soon was developed the world's largest cinchona nursery from which seedlings were distributed to other Latin American republics. Much valuable practical information also was gathered at El Porvenir regarding vegetative propagation, alkaloidal distribution and harvesting and drying techniques. Meanwhile the United States Defense Supplies Corporation established large nurseries of productive Ledgeriana trees in Costa Rica. These were mostly products of the seeds brought out of the Philippines shortly before the fall of Bataan. The plantations thereby established continue under U.S. supervision for 25 years, after which they become the property of Costa Rica. Defense Supplies Corporation also sponsored an Ecuadoran Planting Program, and at least one going nursery was established in that country near El Topo, Province of Tunguragua, on the Río Pastaza.

FIG. 34. An air-view of Tingo María, Peru, where is located one of the more important coöperative Agricultural Experiment Stations in Latin America. In this sort of terrain are to be found large stands of *Cinchona micrantha*, and on the distant ridges in the background *Cinchona nitida*.

At Tingo María, in the Huallaga Valley of central Peru, a coöperative Peruvian-U. S. Government (Office of Foreign Agricultural Relations) Tropical Experiment Station was established in 1942, and U. S. agricultural personnel in conjunction with personnel of the F.E.A. Cinchona Mission directed the establishment of nurseries at nearby Fundo Sinchono where succirubra and Ledgeriana strains as well as various Peruvian species are being grown for future distribution. This coöperative center also took over a small but important seed source in the Chanchamayo Valley, the formerly Japanese-owned Punizas cinchona planting where Ledgeriana seed trees of Far Eastern origin have averaged about 7% quinine with certain individual clones producing close to 17% of this alkaloid.

The establishment of nurseries and experimental plantations in the countries mentioned has given ample opportunity, as did the procurement program, for the thorough training of Latin Americans in cultural practices used in cinchona work. Thus there is slowly being built up in this hemisphere something which was practically non-existent a decade ago, namely, a body of agricultural scientists who now are familiar with cinchona culture as applied to Latin American conditions.

The question arises whether cinchona bark will not be replaced by synthetic anti-malarials, such as atabrine and the like or even laboratory quinine which was first synthesized during the war years. As Popenoe points out, the commercial interests, who should know, are continuing their long-term commercial planting program in Central America. But although experimental work at the coöperative agricultural stations in Andean South America continues, it is too soon to see whether the republics where these stations are located will consider the active continuation commercially feasible.

Cinchona research in this hemisphere has taken a new path, and it may be this change in goal which may make it possible for the successful development of a plantation industry in the Western Hemisphere. Instead of repeating the Far Eastern attempt of developing only high-yielding quinine strains from limited stock, which often require special cultural handling and care, the Latin Development Program has taken advantage of the latest and most thorough of all cinchona surveys, that of the recent war, and with many new strains introduced, cinchona-breeding should reach a new level resulting in the production of not only high-yielding hybrids but also of hybrids which are hardier, easier for unskilled growers to cultivate and with heavier bark volume, in which quinine is not the only alkaloid to be sought after but also others fit for synthesis into totaquine. Some of the possibilities are indicated in earlier Tables (see Tables V and VI) where it is evident that certain "run-of-the-mill" wild species, uncultivated up to now, are equals to calisayas to which they may prove more vigorous or hardy in growth. Successful cultivation and hybridization of cinchonas in the Americas will depend on what the future brings from the manufacturers of synthetics.

Coffee Breeding in Java

By constantly improved techniques in selection, cross-pollination and grafting in Java since 1907, and by accompanying studies in flower biology, fruit-setting and fruit-dropping, increased yields up to 100% are now achieved after two or three generations of coffee breeding.

F. P. FERWERDA[1]

Introduction

During the decade of 1932–1942, so abruptly interrupted by the Japanese invasion, three institutes in Java were engaged in coffee breeding, *viz.*, the Experiment Station of Central and East Java at Malang, the Besuki Experiment Station at Djember, both situated in East Java; and the Government Coffee Experiment Station Bangelan near Malang, also in East Java, under the management of the Netherlands East Indies Government Plantations. At Bangelan, the oldest of the institutions, opened in 1901, the breeding work has gone through all stages of development, from the crude methods which prevailed at the beginning of the present century to the perfected techniques of today. Therefore the present historical treatment of coffee improvement will be based primarily on researches performed at Bangelan. At the other two, the private experiment stations, this development proceeded more rapidly because the breeding methods described here under History of Breeding Work were omitted there and the old methods were followed immediately by the modern ones.

The largest part of the coffee acreage in Indonesia is occupied by *Coffea robusta* Linden which has completely replaced *C. arabica* L.—before 1900 the most important species—in the lower regions up to 700 meters elevation where the latter could no longer be cultivated profitably because of the *Hemileia* leaf disease and root nematodes. *C. arabica* can be maintained only in regions higher than 1,000 meters with a pronounced dry monsoon. Besides these two species others of practical significance are *C. excelsa* and a few hybrids, namely, the Conuga hybrids (*C. ugandae* × *C. congensis*) and a few *C. liberica* × *C. arabica* hybrids. The breeding work has been concentrated mainly on the improvement of *C. robusta*, but attention has been paid also to *C. arabica*, especially at the Besuki Experiment Station, to *C. excelsa* and to various interspecific hybrids.

In the course of years an extensive collection of almost all coffee species of the world, including wild and cultivated forms, has been assembled by Cramer in the test gardens of the General Agricultural Experiment Station at Buitenzorg and at the Bangelan estate. This collection has been one of the most considerable sources of initial material for the breeding work carried out at Bangelan itself and at the private experiment stations. A second important source of

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initial material has been composed of *C. robusta* plants, introduced into Java about 1900, and of their first generation descendants grown on various estates.

The wide variation existing between individuals of any one seedling progeny demonstrates that selection in *C. robusta* offers good prospects. Even seedling progenies that have gone through one selection cycle still display such marked variation that 50% of a crop from them is accounted for by 25% of the individuals.

Coffee breeding is a time-consuming business. It takes at least three years from germination of the seed to the time the plant comes into bearing. Furthermore the great differences in yield between one year and another necessitate an observation period of five years or more to evaluate adequately the yielding capacity of a mother tree, seedling progeny or clone. These are the main reasons why coffee breeding has progressed rather slowly and has produced tangible results only after many years.

History

Pre-Modern Methods. Systematic breeding of coffee in Java was started about 1907. Before that year only mass selection was applied, seed of the best trees in commercial plantations being collected and sown in bulk. This rather crude method was replaced in 1907 by another in which the seedling progenies of carefully selected mother trees were grown separately in test plots. After rigorous observations extending over many years, the best progenies were chosen, and from them seed was taken for establishing commercial plantations. Selection was thereafter continued by again choosing outstanding trees of the elite plots. This breeding scheme, primitive though it may have been, represented at that period considerable progress beyond the method previously followed, but in the long run it was not satisfactory.

In 1912 at the Government Experiment Station Bangelan and at a private plantation in Central Java artificial self pollination was performed in order to obtain pure lines. One difficulty in the procedure was that *C. robusta* produces little seed by self fertilization. Moreover, the progeny did not fulfill expectations, and their vigor was disappointing. This method, too, fell into the background, and a program of inbreeding has not been continued long enough to render available the possible benefits of hybrid vigor.

Selection work was next directed into other channels when in 1916 Cramer introduced vegetative propagation as an aid in breeding work. All promising trees were accordingly multiplied by grafting, and the vegetative progenies thus obtained were planted in a large garden, each clone being carefully segregated. Thus, as it were, a living herbarium arose in which every mother plant was represented by its absolutely identical vegetative offspring, growing under identical conditions. Such a living herbarium had tremendous value in evaluating general habit, growth characteristics and resistance to diseases and pests. On the strength of many years of observation a limited number of mother trees was chosen, the seedling progenies of which deserved further testing, and from these elite trees open-pollinated seed was taken. The resulting seedlings were compared in trial fields, the progeny of each plant occupying one or two plots of 0.4 hectare each.

In the course of years hundreds of progenies have been tested in this way at the Government Coffee Station Bangelan. They have exhibited, in general, great variability, which is not surprising in view of the pronounced tendency of *C. robusta* toward cross-pollination. Among the numerous seedling progenies only a few considerably surpassed the original material in productivity and other respects. In order to reproduce

these outstanding progenies on a large scale, Cramer went back to the mother trees that had produced them. These were increased vegetatively, and the grafts thus obtained were planted in monoclonal fields of one hectare. As soon as these plots came into bearing, seed was collected from the inner trees and used for planting on a commercial scale. The basic assumption was that if a given mother tree had produced a valuable F_1 under open pollination, the F_1 under self pollination in the clonal seed gardens would also possess superior qualities. This reasoning, however, was not entirely correct, principally because:

a). No account is taken in it of the influence which the male partners of open-pollinated mother trees undoubtedly exercise on the composition of the new progeny.

b). The seed formed in monoclonal seed gardens results mainly from self pollination and consequently is not identical to seed derived from open pollination and used in testing the seedling progenies of separate mother trees.

c). The harmful effect of inbreeding, which must be taken into account in such a pronounced cross-fertilized species as *C. robusta*, is overlooked.

At the time that this selection method was introduced, the pollination process of coffee had not yet been adequately studied nor could its consequences be surveyed. Nevertheless this method undeniably brought forth important results. It gave seedling strains, the yielding capacities of which exceeded those of the initial material by 25% to 50%. Until the beginning of the thirties these strains were extensively used.

Modern Methods. About 1927, however, the foregoing and not altogether satisfactory breeding system was replaced by modern methods which involve controlled pollination of elite trees and following up the progenies thus obtained. This method was introduced almost simultaneously by the three breeding institutes.

The first step was to select mother trees from superior progenies obtained in earlier stages of the breeding work. In addition, use was made of seedling progenies obtained by open pollination of outstanding trees detected in various plantations in Java and Sumatra. After selection, the new mother trees were propagated by grafting. This grafting was, in the first place, a safety measure, for if the mother tree was lost, its vegetative progeny was available. It possessed the additional advantage that a clone represented by several members allows much better evaluation of habit and other characters than a single mother tree. It must be emphasized, however, that the final evaluation of a mother tree was based upon observations made on the original tree itself as well as on the clone derived from it.

In the course of the observation period, which in general extended over five years, many mother trees were rejected. This is indicated in Fig. 1 by a slanting line. In judging the merits of the trees, productivity was considered in the first place. Relative productivity was stressed more than absolute productivity, that is to say, the yield of a mother tree was compared to that of neighboring trees of the same age, grown under similar conditions. This relation was expressed as a productive index. A productive index of 200 means that the yield of the mother tree in question is twice the average yield of the trees in the garden where it grew. As a rule mother trees with a productive index below 300 were rejected. The regularity of fruit bearing was also taken into account. Trees that yielded a large crop one year and almost nothing the next were regarded as undesirable. Furthermore, the size of the beans, the turn-out, the habit of the tree and its resistance to disease and insect pests also carried weight.

Among the mother trees that stood this severe test, several cross combinations were made by means of controlled pollination. The technique of this operation was simple. The flowers were castrated one day before they opened, when the buds were in the so-called "candle stage" and were easy to handle because of their fairly large size. The top of each bud was gently bent to the right and left and slightly twisted, thereby breaking the corolla tube just above the ovary. The corollas with their adhering stamens could then be easily lifted so that only the style of each blossom remained. The flowering branches thus emasculated were next wrapped in tightly woven cotton bags supported by rattan hoops. The foregoing is the procedure generally followed today.

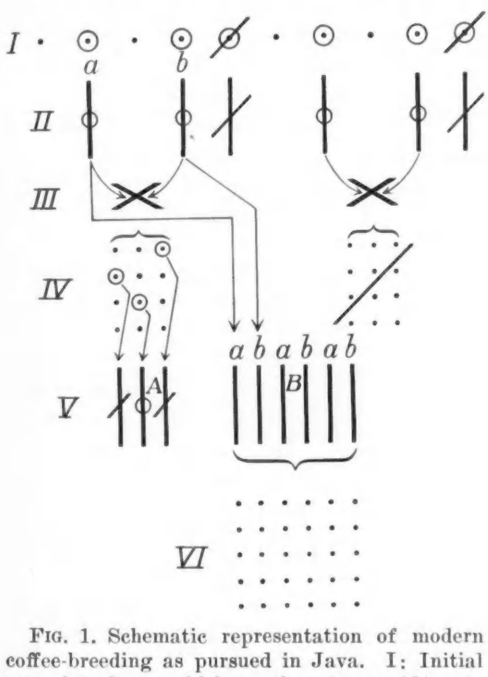

FIG. 1. Schematic representation of modern coffee-breeding as pursued in Java. I: Initial material from which mother trees (O) are selected and others rejected (/). II: Testing of clones. III: Crossing. IV: Testing of F_1 progenies and selection of new mother trees (O). VA: Testing of secondary clones. VB: Seed of the cross a × b is increased by means of bi-clonal seed-gardens. VI: Commercial plantation of seedlings a × b. (Adapted with slight modification from Wellensiek, 1934).

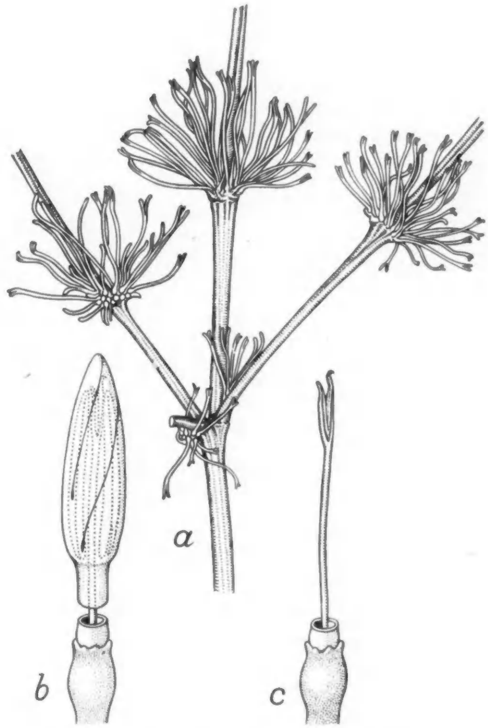

FIG. 2. A branch of *Coffea robusta* with emasculated flowers, about half natural size. To effect emasculation, the unopened corolla with adhering stamens is lifted (b), leaving the flower emasculated with the bifurcations of the stigma sticking together (c).

In spite of the rather drastic treatment involved in this procedure the stigmas develop normally and the next day can receive the desired pollen which is applied by means of a fine brush. Then the bag is closed again. After a week it can be removed, since the stigmas by then will have withered and will no longer be receptive.

With a pronouncedly self-sterile species, such as *C. robusta* and *C. excelsa,* emasculation may be omitted. If many crosses must be made, this simplification means considerable economy, but in experiments of particular importance it is preferable to practise the safe method of castration. In general, setting on artificially pollinated branches is excellent, percentages of 50 to 60 being not excep-

tional. For further details concerning hybridization methods, see citation No. 14.

The F_1 progenies of these crosses are planted in test gardens with three to five replications. The size of the plots is determined by the quantity of seed obtained in the crosses. At least 100 trees of each F_1 generation are planted. Usually some well known strains or standard clones are included as checks.

The F_1 seedlings exhibit fairly large variation, but it is remarkable that in the progenies obtained by pollinating a given mother tree with pollen from several male partners the characteristics of the female parent clearly show up, and all progenies from the same mother show definite resemblance.

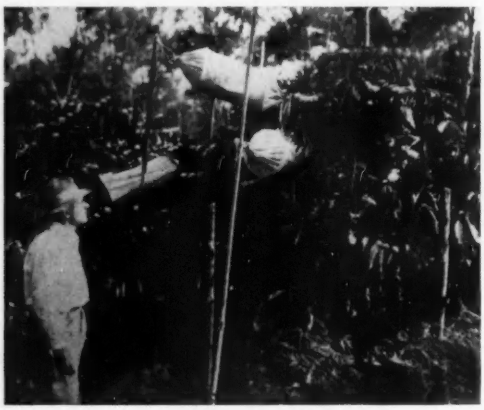

FIG. 3 A specimen of *Coffea robusta* with branches bagged for test-crossing.

The F_1 families are carefully investigated during a number of years; yields are recorded, and characters such as shape and size of the beans, and resistance to disease and pests are studied.

Considering each family as a unit, the yields vary from poor to very good. The mean productivity of all families is slightly above that of the initial material. Only rarely does one meet in a series of F_1 families a few which are so productive as to surpass considerably the initial material. Such families deserve large scale testing, but for this purpose they must first be multiplied. The way in which this is done is later treated in detail. Such cases are exceptional, and in general one has to be content with a series of F_1 families of average nature. These are observed tree by tree. Those trees that considerably surpass the others are chosen as mother trees, and with these new progenitors the scheme indicated earlier is repeated. Continuing in this manner one arrives in the F_2 or F_3 at strains that, though somewhat heterogeneous, excel as a whole and can be considered for many extensive tests and eventually for the layout of commercial plantations. To that end they must be reproduced on a large scale. Seed-gardens are established for this purpose in accordance with the principle that if in the test crosses it has been demonstrated that tree A crossed with tree B has produced an outstanding F_1, then seed identical to that which was obtained in the cross can be grown on a commercial scale by intermixing clone A and clone B and allowing them to fertilize each other, while eliminating extraneous pollination.

Theoretically self-fertilization also takes place within a clone mixture, but since *C. robusta* is decidedly self-incompatible, self-fertilization may be discounted in this species, and the majority of the seed produced by such mixed plantations may be considered to result from a cross between A and B.

The drawback of such plantations is that one has to wait about five years before they yield seed. This difficulty can be removed by the use of so-called "plastic" seed plots on a principle indicated by Hille Ris Lambers (25). The procedure is as follows. At the start of the test cross scheme the clones of the female parents are vegetatively multiplied, and the grafts thus obtained are planted in monoclonal blocks. When the testing of the seedling progenies is finished and one knows which families ex-

cel, the combination A × B can be made on an extensive scale by artificial pollination of the inner trees of the monoclonal block A by means of pollen derived from the clone B. For this purpose hand-dusters are used by which the chosen pollen is blown on the stigmas of the mother clone. This method has proved to be very practical, though it has not yet been applied as much at it deserves.

The above-mentioned elite seedlings, the seed of which can be produced in any desired quantity by means of clonal seed-gardens, are not immediately fit for planting on a commercial scale. Before this can be done their suitability to local conditions must be investigated. The importance of this becomes manifest when we remember that in one coffee-growing region climate and soil may show considerable differences; even the sections of one estate may greatly vary. A newly selected family can give excellent results under one set of conditions but may be unsatisfactory in another environment. For this reason it is necessary to test promising new families on different soils and in different climatological circumstances. Such testing has been pursued since about 1935 by the experimental stations of Malang and Besuki, and on many estates local test plots have been laid out in which the new elite lines of the three selection institutes are more closely investigated, the factor of "local suitability" being especially stressed. On the strength of the data thus obtained it is possible to determine which seedling families are adapted to a given region.

Though these experiments, which constitute more or less the keystone of the work, are by no means completed, a few preliminary conclusions may be drawn. The most important is that some lines are definitely adjusted to a given type of soil and climate; others, on the contrary, accommodate themselves to widely divergent conditions. The result of more than thirty years of this selection work is that families have been obtained which exceed the original material in yield by 50% to 100% and which can always be reproduced pure by means of the above-described clonal seed-gardens.

Up to now selection has been directed mainly towards increasing productivity. Improvement of quality has received attention mainly at the Besuki station. Through careful selection it has been possible at this Station to increase the size of the bean and to combine this character with high yield. Especially for the Besuki district, where the climate has a reducing effect on the dimensions of the beans, these large-beaned varieties are of great value. For further particulars concerning this important selection work the reader is referred to Schweizer (37) and 's Jacob (28).

Plant breeding is a dynamic process. Irrespective of the results obtained the true breeder always aims higher. This happened with coffee breeding in Java. In the middle of the thirties the three breeding institutes made a large number of crosses between mother trees chosen from the best families that were available at that moment. The progenies were planted during the years preceding the war in test plots which reached the productive stage during the Japanese occupation. Our expectations concerning this outstanding material, comprising several hundred families, were very high. Unfortunately the war made it impossible to observe these plants and to collect data. We now must wait to see what has remained after all the recent years of senseless destruction and neglect.

Interspecific Hybrids in Coffee. Spontaneous interspecific hybridization in coffee occasionally occurs where various species grow in close proximity to each other. The oldest known such hybrids are those between *C. liberica* Bull. and *C. arabica*, observed for the first time in 1888. Of more recent date are the *uganda-congensis* hybrids which were

noticed about 1915 by Cramer (3). Besides these a few other species hybrids have been recorded of which we mention here only *robusta × arabica*, *robusta × excelsa*, *arabica × stenophylla*.

Interspecific hybrids all have one difficulty in common. They produce, when propagated by seed, a very heterogeneous, largely worthless offspring. For the maintenance of valuable types one depends on vegetative propagation (grafting). The two species hybrids first mentioned, however, have found acceptance on a limited scale. They yield a crop surpassing that of *C. robusta* in quality, though always inferior to that of *C. arabica*.

Because of their slight susceptibility to the *Hemileia* leaf blight, the *liberica-arabica* hybrids were a boon in the nineties when this dreaded disease wrecked the arabica plantations. A drawback of these hybrids, however, is that they produce many defective spongy seeds, so-called empty beans, which reduce the yield. These seed defects will be discussed later.

In 1923 Arisz and Schweizer (1) made the first successful crosses between *C. robusta* and *C. arabica*. Later a few other species crosses were made by Hille Ris Lambers and Ferwerda. These new hybrids, too, suffer from empty bean formation. The development of interspecific hybridization work was hampered by the lack of an adequate cytological basis. This gap was filled by the cytological work also discussed later. The war, however, has made it impossible to profit from the acquired knowledge.

For practical use one still depends mainly on the old spontaneous *liberica-arabica* hybrids and upon the *uganda-congensis* crosses which latter have spread under the name of "conuga".

Selection of Clones

In the breeding scheme already described vegetative propagation is applied only as an aid. In addition, the use of clones has developed into an independent cultural practice.

The main advantage of clonal material lies in its uniformity which manifests itself not only in similarity of morphological characters, such as leaf shape and tree habit, but also in physiological properties such as time of ripening and flavor of the product.

In a pronouncedly cross-fertilized species like *C. robusta* it takes much time to develop strains breeding true to type. This holds particularly for subtle characters such as flavor. By means of clones, however, one can quickly get homogeneous material. All one has to do is to pick out mother trees having the desirable qualities and to multiply them vegetatively. The chances are that the clones thus obtained will also possess these qualities. One has, however, no absolute certainty on this score; physiological characters, such as productivity and aroma, are not always transferred unchanged to the vegetative descendants. The cause of this is still obscure, but it seems natural to look for an influence of the stock or to hold the process of vegetative propagation by itself responsible. Little study has been made on these problems in coffee. By clonal propagation it is possible to fix and multiply existing types, but not to create new types. To achieve this, one must have recourse to artificial crossing. Those of the resulting individuals which combine the desirable qualities can then be propagated as clones. Both aspects of breeding work, the vegetative and the generative, are thus intimately associated.

Grafting of coffee was put into large scale practice for the first time about 60 years ago in order to multiply the *Hemileia*-resistant interspecific hybrids discussed in the first part of this paper. Interest in it diminished when around 1900 *robusta* coffee appeared on the scene.

Inspired by the results attained in fruit culture in temperate zones Cramer (2) brought the vegetative propagation of coffee again into prominence about 1916. He had test gardens laid out at Bangelan involving several hundred clones of *C. robusta* as well as of other coffee species. The clones were planted in quadrats. The most common size was a plot of 16 trees; more important clones received experimental plots of 49 or 100 trees, while of outstanding ones fields of one hectare (1,100 trees) were planted. Differences due to the heterogeneity of the environment were counteracted by two or three replications.

The clone test gardens were established for two purposes. In the first place they served as aids in seed selection; secondly they were used to evaluate the merits of the clones. The productivity, especially of large monoclonal plots, was disappointing, and it was not possible at first to explain this. It was not until about 1932 that further investigation (9, 23) demonstrated that the pronounced self-incompatibility of most domesticated coffee species[2] except of *C. arabica* must be considered as the main cause of the poor bearing of monoclonal units.

Once this fact was recognized the method of growing clones had to be altered radically. Monoclonal planting was replaced by the planting of mixtures of clones flowering at the same time and capable of cross-pollinating each other. The pollination requirements of the various clones were determined by means of test crosses so that it is possible now to designate the clones suited to be mixed. For further details see citations 9 and 23.

As a crucial test of the conclusions drawn from the pollination research, Ferwerda (17) performed some comprehensive experiments, involving acreages on a commercial scale, in which three to five replications, several clones, single and in mixture, were compared. The results corroborated the theoretical expectation. When mixed most clones yielded two to three times as much as when planted alone. This holds for *robusta* as well as for *conuga*. With self-fertile *liberica* × *arabica* hybrids, as was to be expected, no increase in yields could be observed.

The new insight into the pollination phenomena has radically altered the way of testing clones. The old test gardens composed of monoclonal plots were replaced by modern gardens in which the clones are planted in single rows. This assures the necessary cross-pollination, while differences due to soil heterogeneity may be eliminated by randomization and by a sufficient number of replications.

It would lead too far to treat in detail the results of the clone selection thus executed. For further reference see citations Nos. 13, 27, 42, 44.

It suffices to point out that the modern coffee clones, provided they are planted under optimal pollination conditions, equal the best seedling families in yielding ability. Besides, they have the advantage of absolute uniformity which expresses itself among other things in simultaneous ripening and equal size of beans. A few details concerning the practical application of clonal material will be mentioned later.

Clonal selection offers many further prospects. Especially during the years preceding the war much activity was displayed in this field. New clone testing fields comprising hundreds of new clones were laid out by the three breeding stations. When the war broke out, the evaluation of these clones had

[2] Up to now it has been ascertained that the members of the *canephora* group (*C. canephora*, *C. ugandae*, *C. quillou* and *C. robusta*) are strongly self-incompatible. The same holds for *C. excelsa*, whereas the fertilization properties of *C. liberica* are still in doubt. The *liberica-arabica* hybrids are self-compatible; *uganda-congensis* (conuga) hybrids, on the contrary, self-incompatible.

not yet been completed. It is doubtful that this valuable material has survived the years of Japanese mismanagement followed by a period of political unrest.

Recent Investigations

About 1935 the pioneer stage of coffee breeding was over; the ordinary selection work had been steered into regular channels and developed satisfactorily. Then came the time that research workers had the opportunity to occupy themselves with questions which had arisen during the previous period, the solution of which was necessary for further progress in breeding work. These questions belonged mainly to two categories:

a). Problems connected with fertilization, fruit-setting and fruit-development, including the cytological aspects of these phenomena.

b). Problems concerning the methods of vegetative propagation and the relation between scion and stock.

Flowering, Fruit-setting and Fruit-development. In regions where the contact between dry and wet monsoons is pronounced[3], as in the main coffee-growing centers of Central and East Java, flowering of most coffee species is consummated within a few days at the end of the dry season. Where such a seasonal contrast is lacking, coffee blooms all year round, though here, too, periodic flowering maxima occur.

The cause of this remarkable periodicity of flowering, which no doubt is connected with climatic factors, has not yet been ascertained. Schweizer (39) has tried to relate this rhythm to the osmotic value of the tissues in various parts of the plant. The development of the flower buds in *C. robusta* and *C. excelsa* has been studied carefully by van der Meulen (33), and he comes to the conclusion that the buds are laid down at the beginning of the West monsoon but that they are completely differentiated only in March, *i.e.*, when the heaviest rains are over. During the ensuing East monsoon they remain in a dormant condition from which they are awakened by the first rains announcing the approaching West monsoon. A week later the coffee bushes are in full bloom.

Flower Biology. Various investigators (14, 22, 24, 43) have reached the conclusion that pollen transfer in *C. robusta* is accomplished mainly by wind and that insects play an insignificant part in it.

By means of experiments with glass slides covered with a sticky substance and placed at various distances from a flowering coffee garden, pollen transportation by air was investigated by Ferwerda (14) and Snoep (43). The former could demonstrate that a comparatively large amount of coffee pollen floats in the air for distances up to 100 meters. This pollen cloud rises fairly high; a considerable amount of it was collected on slides eight meters above the ground. From this we may conclude that pollen can easily circulate above the coffee bushes, and that under favorable atmospheric conditions the amount of wind-borne pollen is enough to meet requirements of every stigma. Besides this the quantity of pollen descending from higher branches to lower ones is considerable. This, however, has no significance for fertilization in *C. robusta* and other self-incompatible species, but in self-fertile species, such as *C. arabica* and *liberica-arabica* hybrids, this pollen fall is important.

On the longevity of coffee pollen a few older data (1, 7) are available. The latter investigators preserved coffee pollen four weeks over phosphorus pentoxide, and used this method to perform crosses between *C. robusta* and *C. arabica* when flowering in the two species did not take place at the same time.

[3] In East and Central Java the East monsoon (dry season) holds sway approximately from May till November; the West monsoon (rainy season) from November till May.

Germinative power and longevity of coffee pollen have been studied in greater detail (15) showing that pollen stored without special precautions loses its germinative power after a few days, while when kept above quicklime its capacity for germination and fertilization is maintained for a month or more. This allows the crossing of coffee species that do not bloom simultaneously or that are at a great distance from each other.

Stigmas remain receptive up to six days after opening of the flower.

Fruit-Setting and Fruit-Dropping.

Of the numerous flowers produced by a coffee bush[4], 20% to 25% of them develop into mature cherries. The remaining 75% to 80% are shed as ovaries or as immature fruits. Sometimes the percentages of setting run as low as 10% to 15%. These low percentages have been discussed at great length and have been ascribed to various causes, the main ones being male or female sterility, obstacles to cross-fertilization, and physiological causes. Microscopical investigations (18, 20, 21) have demonstrated that the female sex apparatus of *C. robusta* only rarely has defects. Male sterility, too, is seldom observed. More important are the other causes. Moist calm weather during flowering hinders pollen transfer from tree to tree. Cross pollination, necessary to good fruit setting, fails to take place at such times, and many stigmas experience only self-pollination which makes for poor fruit-setting.

Undoubtedly atmospheric conditions, favoring or impeding cross-pollination, also control fruit-setting to a considerable degree. But even under optimum conditions only some of the ovaries develop into ripe fruits, for physiological factors come into play; in a given environment a tree of a certain constitution can rear only a definite number of fruits; the surplus is eliminated by shedding.

During the first four or five months of the developmental period, a large number of ovaries and young fruits fall. Then suddenly a second period, characterized by a much reduced fruit fall, sets in and lasts till maturity. Mrs. Frahm-Lelieveld observed in some of the small fruits shed during the first period, a fertilized and already slightly devel-

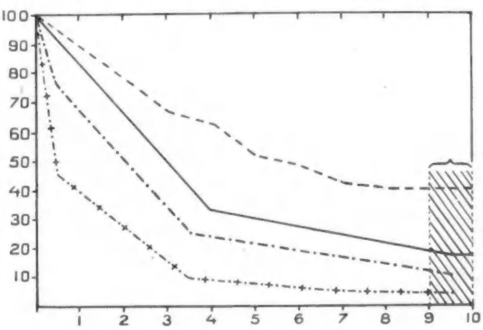

FIG. 4. Fruit-drop in seedlings and in monoclonally planted grafts of robusta coffee. The ordinates indicate the number of fruits surviving 1, 2, 3 etc. months after bloom, expressed as percentages of the number of flowers from which they originate.

——— seedlings, bloom of 1930
+.-.+.-.+ grafts, bloom of 1930
- - - - - - seedlings, bloom of 1932
-.-.-.-.-.-. grafts, bloom of 1932

oped embryo sac. The majority, however, did not show such development. All fruits shed during the second period have well developed embryos. Apparently during the first period, dropping of unfertilized or insufficiently fertilized ovaries takes place, whereas during the second period the surplus of the fertilized ovaries is eliminated. When the results of the various investigators are combined, a remarkable coincidence is revealed.

The sharp bend in the curve of fruit-dropping in Fig. 4 corresponds to the

[4] Counts made on dried bloom clusters disclosed that a normal *C. robusta* bush can easily produce up to 25,000 flowers.

moment when, according to Mrs. Frahm-Lelieveld (18), the endosperm begins to develop, and at which, according to van der Meulen, the differentiation of the new flower buds is completed. Climatologically this is also a remarkable moment because then the period of maximum rainfall is passed and the growing conditions of the coffee plant have be-

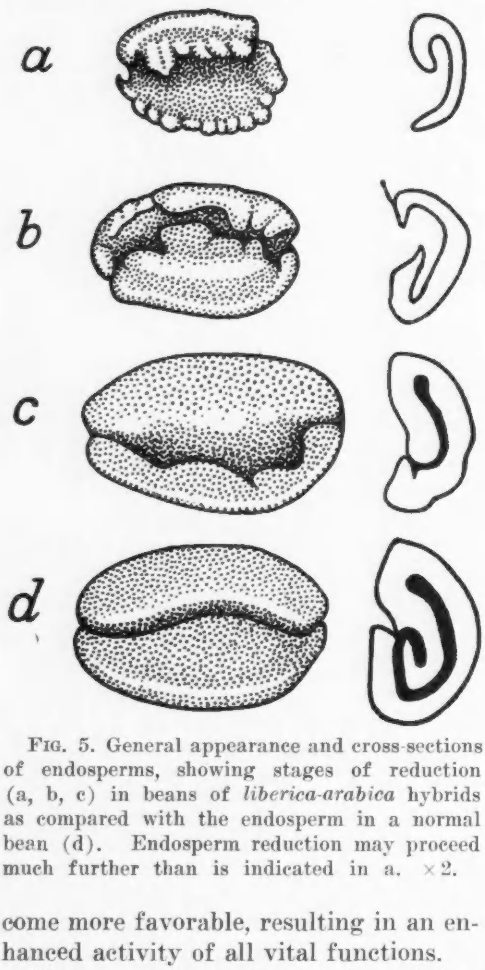

FIG. 5. General appearance and cross-sections of endosperms, showing stages of reduction (a, b, c) in beans of *liberica-arabica* hybrids as compared with the endosperm in a normal bean (d). Endosperm reduction may proceed much further than is indicated in a. ×2.

come more favorable, resulting in an enhanced activity of all vital functions.

Though we are still far from being able to understand the connection between all these phenomena, yet their occurrence is too remarkable to permit our ascribing it to mere chance.

Attempts to promote fruit-setting have not been lacking in Java. The point was to make the two main factors, pollination conditions and general constitution of the tree, optimal. The most important factor, namely, the weather during flowering, cannot be controlled. Occasionally trials have been made to aid pollen transfer when the weather was unfavorable by shaking the trees or by producing a pollen cloud by means of dusters. Striking results are sometimes obtained, but technical difficulties prevent large scale application. The second factor, namely, the general constitution of the bush, can be influenced to a certain degree, for, by means of efficient cultural methods—regulation of shading, treatment of the soil, manuring and pruning—one can endeavor to put the trees into an optimum form. There always remain, however, a certain number of incalculable factors, edaphic and climatological, that cannot be bent to our will. Spraying the young coffee cherries with growth promoting substances, as is done for fruit trees in order to reduce fruit drop, has not yet been tried, and the author is skeptical about the feasibility of this method in coffee culture.

Defective Seed Formation. Not only the shedding of entire fruits but also the occurrence of defective seeds reduces the yield of coffee plantations. Two essentially different types of this faulty formation can be distinguished. The first consists of abortion at an early stage of one of the two seeds which is thereby reduced to a horny pellicle in the normally two-seeded berry or "cherry". Its partner as a result has the entire ovarian cavity at its disposal, and a round, egg-shaped bean develops, which English-speaking planters call a "peaberry". The second kind of seed defect, the so-called "empty bean", arises in a different way. After normal development at first, the endosperm ceases to grow, which is clearly shown by its characteristically notched edge. The result of this defective development, involving sometimes one, sometimes two seeds of a

"cherry", is a poorly filled seed or bean, much lighter in weight than a regular one. In general empty beans have normal embryos.

Whereas peaberries are encountered in almost all coffee species, empty beans are characteristic only of interspecific hybrids and of *C. arabica.* Both seed defects cause a loss of productivity. In the case of peaberry this could be expressed fairly accurately in figures. A simple calculation shows that within certain limits an increase of 1.0% in the proportion of peaberries means a loss of 0.75% in yield. When one considers that peaberry proportions of 40% are no exception, one realizes the loss that this anomaly can cause. The loss of yield resulting from empty beans is less easily computed, because here, besides the frequency of occurrence, the amount of endosperm reduction must also be taken into account. In various cases it could be ascertained that the loss due to empty bean formation attained 30% to 40%.

These two seed defects appeared to be of entirely different origin. Mrs. Frahm-Lelieveld (18) found that unilateral seed abortion, which makes the partner into a peaberry, could be ascribed in most cases to one of two causes, namely, failure of fertilization through either incompatibility or sterility of the embryo sac, and, secondly, non-viability of the zygote.

Researches by Ferwerda (15) demonstrated that in *C. robusta* and *C. excelsa* a pronounced negative correlation exists between fruit-setting and peaberry percentages. A low fruit-setting percentage coincides practically always with a high percentage of peaberries. It is especially after self-pollination that the proportion of peaberries is high.

Both investigators come to the conclusion that the occurrence of peaberries in the produce is the result of unfavorable pollination conditions which act in two ways. They not only occasion poor fruit-setting but also reduce the number of seeds per berry.

The cause of the formation of empty beans appears to belong to an entirely different province. Ferwerda (15), investigating *liberica-arabica* hybrids, did not find any relation between the percentage of fruit-setting and the percentage of empty beans. With self-pollination as well as with cross-pollination, with good as well as with poor fruit-setting, the proportion of empty beans remained about the same. Judging from what is known about interspecific hybrids in other plants, he thought it probable that empty bean formation has a cytological basis and is due to the incompatibility of the chromosome sets of the parents. The cytological research of Mrs. Frahm-Lelieveld (18) have confirmed this supposition. She discovered in the endosperms of these interspecific hybrids aberrant chromosome numbers, indicating that irregularities enter into play which may be the cause of this seed defect. As yet, however, we are not able to form an exact idea of all the interrelations involved. Many obscure points await elucidation. Because of the war this cytological research, unfortunately, had to be abandoned.

As to cultural methods to combat these seed defects, with regard to peaberry the outlook is not very hopeful. Weather conditions during flowering have a predominating influence, and they cannot be controlled. With respect to empty beans, the chances are better. It will be necessary to evolve new, more balanced hybrids. Many cytological researches (8, 18–21, 29, 31, 32) provide a solid foundation for further work. In breeding interspecific hybrids one no longer has to operate empirically. Colchicine treatment, with which Krug (30) has already obtained some important results, may constitute a valuable aid.

Grafting. For the vegetative propagation of coffee cleft-grafting is almost

exclusively used in Indonesia, since experience has demonstrated that it gives the best results. It is not a matter of indifference from which part of the mother tree the scion is taken. Scions from orthotropic water shoots, originating on the mainstem, produce grafts that develop into normal trees. If on the contrary, the scion is taken from plagiotropic branches, grafts result that do not form a real stem but creep on the ground. These abnormal grafts are called "pancakes" by the planters. Because of its disadvantageous form the fruit-bearing surface of such a bush is very limited and production exceedingly low, so that these side-branch grafts are rarely made in practice.

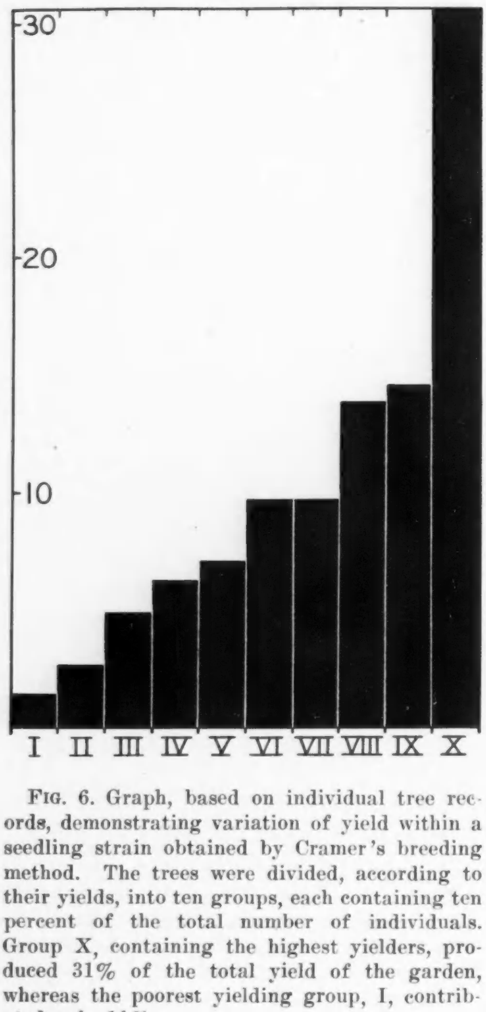

FIG. 6. Graph, based on individual tree records, demonstrating variation of yield within a seedling strain obtained by Cramer's breeding method. The trees were divided, according to their yields, into ten groups, each containing ten percent of the total number of individuals. Group X, containing the highest yielders, produced 31% of the total yield of the garden, whereas the poorest yielding group, I, contributed only 1½%.

About 1928 a planter from East Java found that scions taken from side-branches making an angle of 45° or so with the main stem produce excellent results. These grafts grow vigorously and bear fruit after two years. It is true that the bushes which thus originate have a somewhat irregular form, but this is no drawback in practice.

When the merits of this kind of graft were recognized, the method spread rapidly, and from about 1935 it has been increasingly used. To Hille Ris Lambers (26) and Meyer (34) goes the distinction of having thoroughly studied the morphology of the various types of scions and the development of the grafts obtained herefrom.

The practical aspects of grafting will be treated at greater length in a future article. Grafting is mainly applied for the improvement of seedling plantations. Even modern selected seedling families are still fairly heterogeneous and contain a number of individuals that are inferior in yield and other characters. This is clearly demonstrated in Fig. 6, from which it can be seen that 50% of the total yields of the plantation is produced by 24% of the individuals, and 90% by 75% of the individuals. The remaining 25% of the trees consequently contribute practically nothing to the yield. These "non valeurs" can be made productive by stumping and subsequent grafting with valuable clones. To this end one may take scions from water shoots as well as from erect side branches. In the first case the tree is stumped knee-high, and a limited number of the water-shoots developing after this treatment are grafted. In the second case grafting is done at the height of one to one and a half meters, and the original stem is preserved. This method, the merits of

which have been discussed (5, 9, 10, 38), has lately been finding more and more favor. In some cases as much as 50% of the trees have been regrafted. The results are striking and become evident after a few years.

Gardens planted exclusively with grafts, made beforehand in a nursery, have been established merely on an experimental scale. Only here does the clonal material appear to full advantage.

In grafting the stock is as important as the scion. The basis to the study of the problem of stocks was laid by Cramer (4).

We now have some idea about what happens when one species is grafted upon another. We know, for instance, that *C. robusta* grafted upon *C. excelsa* gives bad results, though there are exceptions to this rule. Conuga, on the contrary, lends itself very well to grafting on *C. excelsa* and so do the *liberica-arabica* hybrids. In the species *robusta* a few strains have been selected (Bangelan 124–01 and Sumber Assin 109) which are very satisfactory as stocks for *robusta* clones. However, these strains have the disadvantage of being heterogeneous, and the ideal, "to every clone an appropriate stock", is far from being realized.

The lack of adequate methods of vegetative propagation of stocks impeded the broadening of our knowledge regarding the mutual effect between scion and stock. The last years before the war this difficulty was removed when Roelofsen and Coolhaas (1939) developed a practical method for growing cuttings under glass, while at Bangelan results have been obtained with etiolated layering. The former method closely resembles the procedure used in Central Africa for *C. arabica.* It now is possible to raise vegetatively propagated rootstocks, but the war unfortunately prevented establishment of systematic rootstock-experiments with this promising material.

Summary

In coffee breeding crosses are today made between outstanding mother trees, and the progenies thus obtained are subjected to comparative tests. Out of them new mother trees are chosen with which this selection process is repeated once or twice. After two or three such generations one arrives at progenies considerably surpassing the initial material in yielding capacity (up to 50%) and other properties. These outstanding families are reproduced on a large scale in clonal seed gardens containing grafts of both parents. Before planting the new seedling progenies on a large scale, it is important to test their local suitability. A few spontaneous interspecific hybrids have also been used in commercial plantations but only to a limited extent. The material secured from artificial interspecific crosses offers prospects but it has not yet gone beyond the experimental stage.

Pollen transfer in the pronouncedly cross fertilizing *C. robusta* is accomplished mainly by wind. Under favorable weather conditions the amount of pollen thus carried is sufficient.

Fruit-setting is determined mainly by two groups of factors, viz., weather conditions during flowering; edaphic and climatological factors governing the physiological processes in the coffee plant. The first mentioned factors determine the percentage of ovaries that will be effectively fertilized, i.e., through cross pollination. The second group decides the percentage of effectively fertilized ovaries that will develop into mature fruits.

Under normal conditions 100 flowers yield 25 ripe cherries; the others drop. This fruit dropping occurs in two sharply separated periods. During the first period mainly unfertilized or incompletely fertilized ovaries are dropped; during the second half-developed cherries are discarded.

Defective seed formation is very important for a crop like coffee in which the seed constitutes the market product, and two types of seed defect must be distinguished, viz., unilateral complete abortion which causes the second seed to develop into a so-called peaberry, and empty bean formation which is characterized by incomplete development of the endosperm. Both defects cause considerable loss of yield. Peaberry is mainly due to self-pollination, whereas empty bean seems to rest on a cytological basis.

Cleft grafting is the most successful means of vegetative propagation. In the plantations vegetative propagation is mainly applied for top-working, worthless individuals occurring in seedling gardens.

The fundamental problems concerning the reciprocal influence of scion and stock have not yet been adequately studied. We know something about the behavior in intraspecific grafting, while further a few robusta strains have been bred, which give satisfaction as stock for many clones.

Lately methods have been developed enabling the vegetative propagation of rootstocks. The war has prevented the performing of experiments with this promising material.

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The Castor-Oil Plant in the United States

About 125,000,000 pounds of castor oil are annually used in the United States in the manufacture of paints and varnishes, fatty acids, sulphonated oils, soap and other important products, 95% of which is imported either as seed or expressed oil. Attempts are now being made to revive a former American industry in the growing of domestic crops.

R. O. WEIBEL[1]

Description of the Plant

THE castor plant, *Ricinus communis* L., is not a legume or "bean", as it is often called, but a member of the spurge family, Euphorbiaceae. The name "Ricinus" is a Latin term meaning "dog-tick", and was bestowed upon the plant by Linnaeus because of the resemblance of its seed to that canine pest.

The plant is a coarse perennial (treated as an annual in temperate climates), bearing large, alternate, palmately lobed leaves, flowers in large terminal clusters, and varicolored seeds in prickly or smooth three-membered capsules. In tropical climates the plant grows to heights of 30 to 40 feet with stems three to six inches in diameter. In temperate climates it behaves as an annual, and heights of three to eight feet are more common. Male flowers have branched stamens and occupy the lower, female flowers with branched stigmas, the upper part of the axis of the inflorescence. Seed varies in size from 450 to more than 5,000 to the pound, depending upon variety and seasonal conditions; commercial varieties average roughly 1,000 to 1,500 to the pound. Seed color consists of a base color which ranges from white, gray, brownish yellow, brown or red to black, and an outer pattern color of gray or brown to black. The pattern itself varies from fine to coarse veined or finely dotted to large splotches.

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Historical Background

The castor plant is not indigenous to the Western Hemisphere but is believed to have been introduced at a very early date. Just when castor seeds were brought into the United States is not known. It has been a minor crop, limited at even its highest stage of development to groups of counties rather than to States, and its early history has not been recorded. These early localized areas were for the most part in Illinois, Missouri, Kansas and Oklahoma. It was not until 1850 that data indicating geographical distribution and extent of the crop were available. By 1850 there were 23 castor-oil mills in the United States, located in Illinois, Missouri, Virginia, Ohio, Tennessee, Pennsylvania, Alabama and Arkansas. St. Louis was the commercial center in the West, and seventy percent of the domestic production of castor oil was there. Production became spasmodic, and areas of production shifted so that by 1870 there were only six mills in operation, three of them in Texas and one each in Missouri, New Jersey and Tennessee. New mills on the east coast to handle imported seed operated more regularly, and for the most part the mills in operation at present are located there. The record of produc-

TABLE 1. PRODUCTION AND IMPORTATIONS OF CASTOR SEED IN THE UNITED STATES*

Year	Seed production in U. S.	Importations	
		Seed	Oil
	lbs.	*lbs.*	*lbs.*
1880	23,759,322†	2,390,000	....
1900	6,595,848	6,779,550	26,208
1920	19,688	30,370,000	792,000
1940	....	307,785,000	382,000

* Data from Yearbooks of Agriculture, Agricultural Statistics and Agricultural Census.
† Amount received at the St. Louis market which represented most of the production.

tion and importations is shown in Table 1.

Incidental mention is found of cultivation of the castor plant in Illinois before the State was admitted into the Union in 1818. Of the 23 oil mills reported in the U. S. in 1850, ten of them were in Illinois. However, by 1870 there were no mills operating within the State. Records of production are available from 1877 to 1916 (Table 2). Production after 1916 was so small that there is not any account of it. During the period 1877 to 1916 the largest acreage harvested was 19,374 in 1886 with 136,518 bushels produced. The highest average yield was reported for the years 1913 and 1914 at 18 bushels or 822 pounds per acre (46 lbs/bu.) The highest average price paid was $1.90 per bushel or 4.13 cents per pound in 1916, and the lowest average price paid was 95 cents per bushel or 2.06 cents per pound in 1896.

The Commodity Credit Corporation in 1943, as a protective measure during World War II, contracted with Illinois farmers to grow approximately 1,000 acres of castor seed. Mason and Cass Counties planted the greater part of this acreage. Cost of production studies (1) were made, and records in detail were obtained from 34 growers who planted an average of 5.4 acres. It cost $20.96 an acre to grow, harvest and deliver an acre of castor plants producing 602 pounds of seed in the hull. Seed in the hull sold for an average price of $5.73 an hundred pounds or $34.50 an acre. The net profit per acre was $13.54. This federally sponsored program was not continued in 1944. There was definite interest shown by the growers in growing castor seed, but marketing problems prevented further production.

Because the demand for castor oil far surpasses the amount imported, the Baker Castor Oil Company, which is one of the largest and oldest companies processing castor seed, has initiated a program of domestic production. Production contracts were let in 1947 with most of the acreage (approx. 400) in Mason County, Illinois. Results of the 1947 crop are not yet available, but continued

TABLE 2. PRODUCTION AND VALUATION OF CASTOR SEED IN ILLINOIS FOR FIVE-YEAR INTERVALS FROM 1877 TO 1916*

Year	Acres harvested	Bushels produced	Average yield	Price received	Value of crop
	no.	*no.*	*bu./A.*	*bu.*	
1877	4,503	17,538	3¼	$1.10	$ 19.512.00
1882	2,088	4,346	2½	1.26	5,476.00
1887	14,978	95.721	7	1.00	95.596.00
1892	5.292	33,961	6	1.40	47,666.00
1897	7,663	71,362	9	1.00	72,966.00
1902	7,156	66,128	9	1.20	79.084.00
1907	7,150	94,848	13	1.30	121,291.00
1912	5,819	69,828	12	1.00	69.828.00
1916	968	13,455	14	1.90	25,500.00
Av. 40 yrs.	6,209.7	57,964.5	9.6	1.28	72,922.00

* Data from Illinois State Board of Agriculture—Statistical Report 915–16.

FIG. 1. (*Upper*). Castor seed yield nursery at Urbana, Ill., approximately 60 days after planting in rows 40 inches apart with plants 20 inches apart within the rows.

FIG. 2 (*Lower*). Castor seed of the Conner variety, four-fifths natural size.

interest is being shown by the growers. The price being paid the growers is 10 cents a pound (minus one-half cent for a hulling service fee) for hulled seed.

Adaptation

Adaptation of the present castor seed varieties, so far as the United States is concerned, has been well determined by studies made by the Bureau of Plant Industry, Soils, and Agricultural Engineering cooperating with State Agricultural Experiment Stations and individuals. These studies were made during the seasons 1941, 1942 and 1943 and have been reported (2). Summarizing briefly from these reports: Adaptation is mainly determined by three major factors, *viz.*, disease, length of growing season and rainfall. Only one disease, gray mold (*Sclerotinia recivi* Godfrey), has been definitely found to be important. This eliminates a sizeable area of the Gulf Coast region from the area of adaptation. Yields of the three common varieties, Conner, Doughty 11 and Kentucky 38, have, in general, been good in areas with growing seasons of at least 180 days, while production has been hazardous in areas with shorter growing seasons. Observations in Kansas, Oklahoma and Texas indicate that 15 to 20 inches of rainfall from April to September are essential to satisfactory yields. These three factors outline an area of adaptation for the present varieties which includes, roughly, the southeastern half of Kansas, Missouri, the southern third of Illinois, southern Indiana, the southern tip of Ohio, the western and central parts of Kentucky and Tennessee, Arkansas, all of Oklahoma, except the Panhandle, and the part of Texas north of Dallas and east of Lubbock and the part within a radius of about 50 miles of Corpus Christi (Fig. 7).

Soils best adapted for castor seed have (*a*) exceptionally good surface and subsurface drainage, (*b*) sufficient subsoil permeability to insure the adequate movement of air and water and the growth of roots, and (*c*) the capacity to warm up readily in the spring. Loams and sandy loams are better than clay loams or clay soils. Castor plants succeed on either calcareous or acid soil if both the surface and subsurface soils drain well.

Culture

Castor seed should be planted on a well prepared seedbed similar to that prepared for corn. Since early planting is desirable, it may be necessary to plow the land in the fall. The date of planting will vary according to the locality, but, in general, seed should be planted as soon as possible after the soil has become warm and danger of frost has passed. The early part of May is recommended for central Illinois. A corn planter with special plates is used for planting the seed. The planter plates should be thicker than the normal corn plate to prevent breaking or crushing the seed. The seed contains a high percent of oil, and if crushed the oil will cause dirt and dust to collect which may clog the machine. Seed should be planted from one to two inches deep and at a rate which will space plants from 18 to 20 inches apart in rows 40 to 42 inches apart. Because the seed is variable in size and quite commonly low in germination, it is necessary to know the percentage germination and then to adjust the planter to drop the desired number of seeds.

Castor plants should be cultivated shallow with ordinary corn equipment and often enough to control weeds. Castor plants normally require less cultivation than corn, since their rapid growth shades the ground much earlier in the season, thus checking weed growth.

At present castor seed must be harvested by hand, although research is under way to develop a mechanical

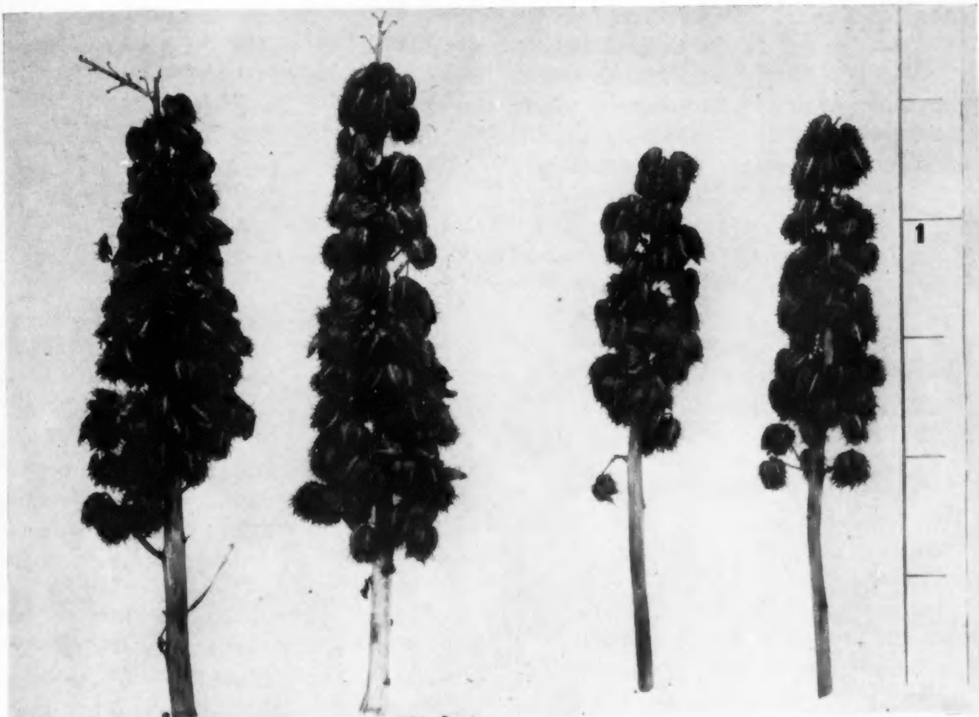

FIG. 3 (*Upper*). Typical mature seed spikes of two varieties of castor plant, Conner on left, Kansas Common on right. Cut Dec. 1947 from plants grown in the 1947 nursery.

FIG. 4 (*Lower*). Variations in spikes of the castor seed plant: typical spiny on left, typical spineless next, loose spike in center, and variation in size and compactness at right.

method of harvesting. In hand-harvesting the spikes are cut or broken off, and the capsules are stripped off into a wagon or sled. In some cases the capsules have been stripped by hand directly from the plant and dropped into containers carried or strapped to the worker. This works well unless spikes are too large. Unless the capsules are dry, they must be spread out so that they will dry quickly. After harvesting the seeds must be removed from the capsules. Hulling machines are available which do satisfactory work if the capsules are dry. The percentage of seed to hull will average about 65 to 75, depending upon the maturity of the seed at harvest.

Observations indicate that castor plants produce more seed on soils of average than of high fertility. Highly productive soils, especially if high in nitrogen, produce excessive vegetative growth and late maturing plants. Results to date in Illinois have not shown a significant response to a particular fertilizer or fertilizing element. Phosphorus alone has been reported to have produced significant increases of seed at Princeton, Kentucky (2), but failed to show any increase when used in combination with nitrogen or potash.

Varieties and Yields

There are a great many varieties or types of castor plant, but only two of possible commercial value for Illinois at the present time. These are Conner and Kansas Common. Conner is the taller and later of the two and produces large spikes. At Urbana, Illinois, Kansas Common begins to flower 10 to 14 days before Conner and produces more but smaller spikes. It may shatter somewhat if the mature spikes stand too long before harvest. Yields of Conner and Kansas Common from four locations in Illinois are shown in Table 3. These locations represent four quite different soil conditions: well drained soils of medium fertility at Urbana; tight clay soils of medium fertility at Brownstown; sandy soils at Havana; and upland low fertility soils at Dixon Springs. While soil conditions at Brownstown would not seem adapted, fairly good yields have been obtained. In two of the three years at Havana, the trials were located on very sandy areas and moisture was not sufficient for best yields.

TABLE 3. YIELD OF TWO VARIETIES OF CASTOR PLANTS FROM FOUR LOCATIONS IN ILLINOIS

Variety	3 yr. av. yield, 1944–46 (lbs/A. hulled seed)				
	Urbana	Brownstown	Havana	Dixon Springs	Average
Conner	1713	883	815	510	980
Kansas Common	1657	1140	885	791	1118

Oil content of the seed varies slightly from season to season and from different locations but usually ranges between 50 and 55 per cent. The per cent of oil for Conner and Kansas Common from four locations in Illinois is shown in Table 4. There is little difference between the two varieties, but there is a difference between the locations. Samples from areas of lower yield per acre (low fertility) show a higher per cent of oil.

TABLE 4. OIL CONTENT OF TWO VARIETIES OF CASTOR PLANTS FROM FOUR LOCATIONS IN ILLINOIS

Variety	Percent Oil* 1946 Crop				
	Urbana	Brownstown	Havana	Dixon Springs	Average
Conner	51.3	51.8	55.6	53.5	53.05
Kansas Common	52.3	51.8	54.2	54.5	53.20

* Oil determination made by the Northern Regional Research Laboratory, Peoria, Ill.

Crop Hazards

Investigations by the United States Department of Agriculture in cooperation with experiment stations have brought to light some diseases and insects which attack the castor plant. Gray mold has already been mentioned as a limiting factor in production for certain gulf and southern States. Another disease is induced by *Alternaria ricini* Yoshii which seems to be present in almost every locality, and infection occurs when correct atmospheric conditions exist and tissue of the right maturity is present. Young spikes are often completely killed, so that as long as the optimum atmospheric conditions for the disease exist, no spikes will develop. No definite resistance has been reported.

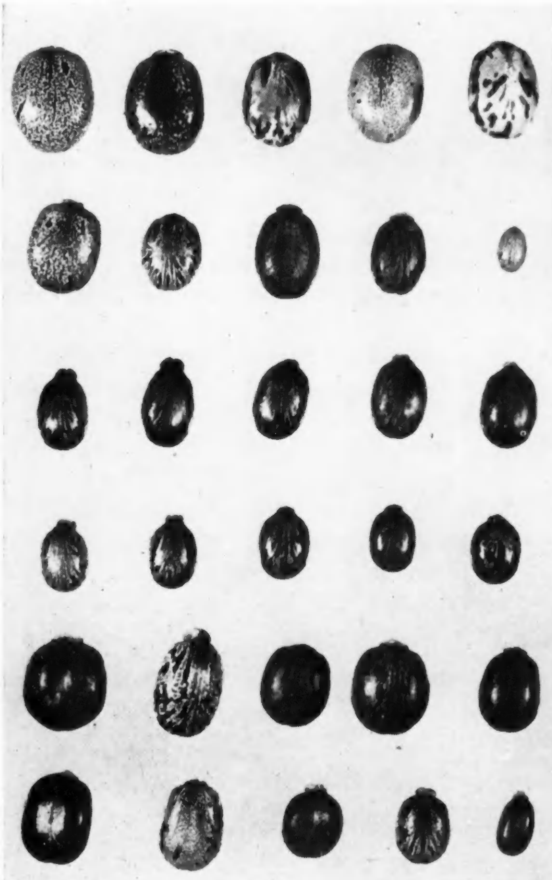

FIG. 5 (*Left*). Variation in seed size, seedcoat color and seedcoat design of castor seed. Third row from top contains seed of Kansas Common (three on left) and of Conner (two on right) varieties.

FIG. 6 (*Right*). A specimen of Kansas Common (Ill. No. 1) castor plant killed by frost and removed from a planting 20 inches apart in rows 40 inches apart.

The root-rot disease of cotton (*Phymatotrichum omnivorum* (Shear), Duggar) also attacks the castor plant. It is not usually so severe as on the cotton plant, but yields have been greatly reduced and quality lowered on root-rot infested soil. Leaf spot (*Cercospora ricinelli*) has also

been reported, but, though widespread, it has with few exceptions not been serious. Seedling diseases have also been reported. Studies (3) indicate that seed treatments are helpful in obtaining better stands.

Numerous insects have been reported as feeding on the castor plant, but the damage done is usually minor. Some of the insects reported are: a green stinkbug of the Pentatomidae, a serious pest in the area of Dallas, Texas; leaf hopper, leaf miners, nematodes and grasshoppers.

Wind storms from mid-summer till harvest are always a potential hazard.

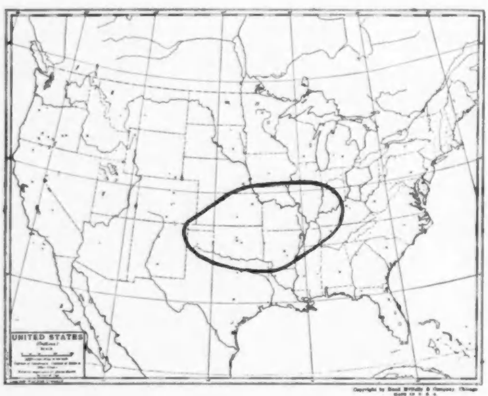

FIG. 7. Approximate area for adaptation of castor seed production, as determined by Domingo and Crooks (2).

Varieties differ in their resistance to lodging, but Conner and Kansas Common have not been seriously damaged. While the writer cannot cite a specific case of hail damage, a plant such as castor would seem very vulnerable. Shattering of the seed or of the capsules may reduce yields considerably. Some varieties shatter their seed as soon as mature, while others shatter very little. Frequent rains followed by bright dry conditions tend to accentuate shattering. The castor plant requires a well aerated soil, and young plants are quickly damaged by flood conditions. While early planting is recommended in order to give the plant the benefit of a long season, the soil should be warm at planting time. Cold wet soil conditions during germination and plant emergence result in much seed rotting in the ground or many seedlings being killed by pre- or post-emergence diseases.

TABLE 5. THE CHARACTERISTICS OF CASTOR OIL*
(Usually within the following limits)

Specific gravity at 15° C.	0.958	to	0.968
Iodine number	82	to	90
Saponification value	177	to	187
Acetyl value	143	to	150
Reichert-Meissl value	0.2	to	0.3
Unsaponifiable (per cent)	0.3	to	0.7
Refractive Index 15° C.	1.4790	to	1.4813
25° C.	1.4771		
40° C.	1.4659	to	1.4730
The oil is dextrorotary			

* From "Vegetable Fats and Oils" by Jamieson, G. S., 1943.

Breeding and Improvement

Breeding work on the castor plant has followed the trend of the demand for castor oil. The demand for castor seed or castor oil has stimulated public interest

TABLE 6. THE COMPOSITION OF CASTOR OIL*

	Percentage composition as reported by		
	Eibner & Munzing[a]	Ponjutin & Rapoport[b]	Kaufmann & Bernhardt[c]
Ricinoleic acid	80	86.0	87.0
Oleic acid	9	7.0	8.4
Linoleic acid	3	3.5	3.1
Stearic acid	3	0.3	....
Dehydroxystearic acid	....	1.8	0.6
Unsaponifiable acid	....	1.8	....
Saturated acid	....	....	2.4

* From "Vegetable Fats and Oils" by Jamieson, G. S., 1943.
[a] Eibner and Munzing-Chem. Absts. 19, 3027 (1925); J. Soc. Chem. Ind. 44, B679, 1925.
[b] Ponjutin and Rapoport—(Chem. Uraschau, 37, 130 (1930)).
[c] H. P. Kaufmann and H. Bernhardt—(Fette u. Seifer, 46, 444 (1939)).

at various times, and experiment stations within the area of interest have given some time to its improvement. In most cases the interest has died out before the plant breeder had an opportunity to advance very far towards the development of better adapted types. As a result of the lack of a continuous and coordinated improvement program, progress towards better adapted types has not been very effective. However, some advancement has been made, and types are available which are much better adapted to the temperate climate than the earlier introductions. Definite breeding programs are underway at several locations in the United States at the present time, and with continued interest in domestic production advancement should be more rapid in the next few years.

Very little research on the genetics of the castor plant has been reported by workers in the United States since 1928, and the work prior to that year has been summarized (4, 5). The characters which have been studied include (*a*) leaf and stem color, (*b*) bloom and its distribution, (*c*) spines on the capsules, (*d*) color and pattern of the seed coat, (*e*) leaf shape and (*f*) albinism. In addition to these White (6) has reported studies on dehiscent and indehiscent capsules, seed size, plant size and spike type. Peat (7) reports a linkage relationship between stem color and bloom, the only clear case of linkage noted so far. The haploid chromosome number is given as 10.

More recently Domingo (8) has reported on "Flowerless Castor Bean Plant". The flowerless character was

TABLE 7. UTILIZATION OF THE CASTER BEAN PLANT*

Leaves	Seed		Stems
Insecticide	*Oil*	*Pomace*	Alpha cellulose
	Used in the manufacture of	Fertilizer	Paper
	Hydrated oil (Paints, varnishes)		Wallboard
	Medicinal oil		
	Lubricating oil		
	Sulphonated oil		
	Turkey Red oil		
	Hydraulic fluids		
	Recoil mechanisms		
	Emulsion breakers		
	Fly paper		
	Fly oils and dope		
	Inks		
	Nylon		
	Plastics		
	Perfume aromatics		
	Ointments		
	Toilet creams		
	Hair dressings		
	Soaps		
	Linoleum		
	Oilcloth		
	Artificial leather		
	Leather preservatives		
	Rubber substitutes		
	Electrical insulation compositions		

* This list does not necessarily include all uses made of the castor plant but only those which have been brought to the attention of the writer. The order of uses does not indicate relative importance.

found only in F_2 populations from two closely related sources of parental material. Domingo (9) has also reported on the "Amount of Natural Out-Crossing in the Castor Oil Plant". This study was conducted in the field under Illinois conditions where 36 per cent of out-crossing occurred. White (10) previously reported five per cent of out-crossing in the breeding plots at the Brooklyn Botanic Garden. Weibel and Woodworth (11) have used the Natural crossing plot as a means of making hybrids, a method which has been satisfactory if one male parent was used for a number of crosses, and if a quantity of hybrid seed was desired.

Manufacture of Castor Oil

Before castor seed is processed it is first cleaned to remove foreign material.

TABLE 8. FACTORY CONSUMPTION OF CASTOR OIL THREE-YEAR AVERAGE (1943–45)*

Commodity	Oil consumed
	lbs.
Paint and varnish	48,250,333
Fatty acids	16,839,667
Sulphonated oils	10,517,667
Soap	6,413,000
Printing inks	1,320,333
Linoleum and oilcloth	1,245,333
Lubricants and greases	1.039,667
Miscellaneous	38,859,333
Total	124,485,333

* From U. S. Department of Agriculture, Agricultural Statistics—1946.

Seed is then run through decorticating machines to remove the seed coat from the kernels. The more complete the decorticating process the lighter is the color of the oil. In this process constituents are removed which wear out the equipment. However, a certain amount of fiber present prevents squirting of the meats from the presses and also prevents the introduction of excessive meal into the oil. Because of their nonfibrous character, high oil content and a very active enzyme which releases fatty acids, castor seeds can not be ground and tempered as are flax seed or soybeans. Thus it is desirable to get as many as possible of the seeds to the presses in an unbroken or whole condition. Preheating is necessary but only enough to make the naturally heavy viscous oil more mobile. Seed is next put into the presses. The cage press is the more common type used. Oil obtained is number one oil, but because it is necessary to keep temperatures low a high per cent of oil is left in the press cake. Most of this oil is recovered from the press cake by solvent methods of extraction. The rotary batch extractor is the common type used, and the oil recovered is number three. Oil as obtained is not "finished". Number one oil requires little or no refining but it has to be bleached. Number three oil is refined to remove impurities; it can not be effectively bleached.

Uses

Oil. The important uses of the castor plant have been focused on the seed and more specifically the oil which is extracted from them. Characteristics and composition of castor oil are shown in Tables 5 and 6. Castor oil has unique properties and is one of the most versatile of the vegetable oils. This uniqueness is due to its chemical make-up which is not characteristic of other vegetable oils. The reason is that ricinoleic acid, the principal constituent of castor oil, has a double bond between the ninth and tenth carbon atoms and a hydroxy group attached to the twelfth carbon (13). Removing a molecule of water from the eleventh and the twelfth carbon creates a system of conjugated double bonds.

Castor oil is used in the manufacture of many and various valuable products. A partial list of the uses is shown in Table 7. Dehydrated castor oil is the largest new development for castor oil, with sizeable volumes being used in the conversion to sebacic acid and sulpho-

nated oil. Factory consumption of castor oil as a three-year average (1943–45) is shown in Table 8.

Pomace. After oil extraction the residue is know as "castor pomace". Castor pomace contains a toxic substance, ricin, which makes it unsuitable for livestock feed, but because of its high nitrogen value it is used by the fertilizer industry. According to the 1938 Department of Agriculture Yearbook, castor pomace contains the following percentages of fertilizing constituents: nitrogen, 5.5; phosphorus (P_2O_5), 1.0–1.5; potassium (K_2O), 1.0–1.5. The use of castor pomace as a fertilizer is well established.

Leaves. While attention has been focused mostly on the seed, other parts of the plant have been subjected to research for possible uses. Extracts from the leaves and young stems have insecticidal value (14).

Stems. The stems are a source of pulp and cellulose which can be used in the making of cardboard containers, wallboard, newsprint, Kraft and other paper materials. Miller (15) states that mills designed to use wood as raw material can be readily converted to use castor stems, but that mills designed to use cereal straws require considerable investment before they can handle castor stalks.

The cost of collecting stalks and transportation to mills has been too high in most cases to allow this product to compete sucessfully with existing sources of pulp and cellulose.

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Utilization Abstract

Margarine. In 1870 a French Chemist, Meges Mouries, won a prize offered by Napoleon III for an agreeable substitute to replace expensive butter. The prize-winning product was made by mixing casein, separated from milk, with oleo oil obtained by fractionating beef fat. The inventor named his product "oleomargarine", and from that time until about 30 years ago beef fat continued as the principal ingredient in oleomargarine.

Then deodorized coconut oil, usually along with small quantities of peanut oil, was used in the production of the first margarine containing no beef fat. Coconut oil remained dominant in this use for many years, but the margarine made from it was too hard to be spread below 55° F. and lost its form in hot weather. In recent years it has been displaced by the hydrogenated oils of cottonseed, corn, peanut and soybean. And in Europe refined whale oil is employed for the purpose (*George S. Jamieson, Jour. N. Y. Bot. Garden* 49: 38-40. 1948).

Forest-Tree Breeding

The breeding of forest trees by means of selection and of hybridization in order to obtain increased disease resistance and improved utilitarian qualities in pulp and timber trees is still in the experimental stage, but long-range planning along these lines offers one means of balancing diminishing timber supplies.

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Introduction

Of all the materials and substances made by plants, wood is perhaps the most useful and valuable, with the exception of those used to sustain human life itself. One has only to look about him and see the great variety of objects made of wood and the diversity of its uses to convince himself of the truth of this. And recently the extended use of wood in the manufacture of plastics, plywood, *etc.* has greatly enhanced its intrinsic value. It can hardly be a coincidence that the most progressive nations of the world are the greatest users of wood. The United States utilizes more than one half of all the wood consumed in the world and produces about one half of all the saw timber. It would appear that our progress as a nation is in a large measure dependent upon our supply of wood. But we are at present cutting our saw timber, with respect to its growth, in a ratio of about three to two. Apparently we are using about half again as much wood as we are growing[1].

As regards the money value of wood the over-all figures are not available to the author, but, including all classes and kinds of lumber, there seems to be no question that the money value as a whole since, let us say, 1915 has more than doubled.

Because of all these conditions it is imperative that we utilize every possible opportunity to increase and improve our wood production. The breeding and improvement of our forest trees is therefore of fundamental and urgent importance.

What is Meant by Tree Breeding? One of Webster's definitions of "breeding" is "the propagation of plants or animals, particularly for the purpose of improving them". The layman, however, usually thinks of breeding only in its sexual connotation, as, for example, in the breeding of dogs, horses and cattle. But plants can be bred in the same way and are so treated by plant breeders throughout the globe. This kind of breeding is more accurately known as "hybridization", or, as it has been called, "generative breeding". Usually, along with the process of generative breeding, "selection" goes hand in hand.

Variation. Before we go further we must consider briefly the great fact of variation. This is one of the fundamental phenomena in the world of living things. Everyone is familiar with the oft-repeated saying that no two blades of grass are alike. "No two trees, no two leaves, no two cells in a leaf are identical in every respect". Even identical twins, those which have developed

[1] This is not strictly in accord with facts because after mature trees are felled, the resulting coppice growth much exceeds in its annual increment the growth of the old tree.

from the same fertilized egg, are never absolutely alike.

We know something regarding the causes of these differences, but not very much more than was known 50 or 75 years ago. In general we may say that there are two sorts of differences or variations: one, due to external causes, *i.e.*, to the effect of the environment, and, with some exceptions, not hereditary; the other due to changes in the living protoplasm which can be traced back to the fertilized egg. The latter differences, being due to internal causes, are hereditary. Thus a tree growing in good rich soil with plenty of light, air and sufficient moisture should naturally make good growth. But a cutting from the same tree grown in rocky, poor soil, with little light, will probably make only a puny specimen. This is an example of differences due to environmental causes. The heredity of the two trees is the same since the one grown from the cutting has strictly the same living substance as that of the tree from which the cutting was taken.

Selection. This brings us again to the subject of selection. Where there are many individuals to choose from, one of the problems of the tree breeder is to determine how many of the characters of an individual are due to heredity and how many to environment, for in hybridization he must select the best parents to effect the desired combination in the offspring. Good germ plasm is the fundamental objective, and its effects must be separated from effects of environment. But it should be emphasized that even selection, by itself, is a method of tree breeding. For example, man and other animals, who naturally choose the best for eating, have been breeding fruit and nut trees by selection for ages past, probably since long before recorded history began[2].

[2] We here use "fruit and nut" trees in the popular sense; botanically every broad-leaved tree is a "fruit" tree, since the ripened ovary is a fruit.

Comparison of the luscious apples, peaches and pears of today with the fruits of those trees that represent the primitive wild forms is a good illustration of what this sort of selective breeding has done when persistently employed for thousands of years. As regards some of our magnificent fruits of today it should be stated, however, in fairness to the horticulturists, that such improvement has by no means been all due to selection. Hybridization between species, varieties and individuals has been practised now for about a century; for apples, since 1869; grapes, 1851; pears, 1867; and peaches since about the turn of the century.

The jumbo chestnuts that the "all-hot" man on the street corner roasts on his hot plate are European or Spanish chestnuts (*Castanea sativa*) imported mostly from Greece and Italy. But the original native European chestnut was small, comparable in size to the nut of the American chestnut (*C. dentata*). Long ages of selection have gradually brought these large nuts into being. And so it is with the Japanese (*C. crenata*) and Chinese (*C. mollissima*) chestnuts. The Japanese have more than a hundred varieties of the Japanese chestnut, which they classify as large, medium and small, the result of centuries of selection.

Why Tree Breeding Has Lagged. The thrilling tale of Hybrid Corn has been recounted in the pages of ECONOMIC BOTANY (**1**: 5–19, 1947); how by special methods in which the marvelous phenomenon of hybrid vigor or heterosis is employed, millions of dollars have been put into the pockets of our farmers. In horticulture also, as indicated above, breeding, not only by selection but also by hybridization, has gone on apace, with sustained improvement through the years (See Yearbook of U. S. Dept. Agr., 1937).

But what has been done toward the improvement of our forest trees? Com-

paratively little for a field that gives promise of rich rewards. This paper is an attempt to review briefly some of the more important work here and abroad in this field as well as to explain the technique involved and give suggestions for the future.

What are the reasons for the lag in forest-tree breeding? An underlying cause seems to be the fact that from the time of the first settlers in America, the forests have always been taken for granted. Their extent and richness were tacitly assumed to be without limit. Wood was cheap because there was plenty of it. We all know the story of the reckless treatment the forests of this country have suffered since they first were occupied by the white man.

FIG. 1. Stump of one of the Dunkeld larches, planted in 1738, cut down a few years ago. In 1888 its height was 102 ft. 4 in. and the circumference, 3 ft. from the ground, 17 ft. 2 in. Its volume was estimated at that time to be 648 cubic ft. (*Courtesy C. Syrach Larsen.*)

But long before now foresters and conservationists have seen the handwriting on the wall and have been crying out against the fearful waste. State and Federal Forest Reserves have been set aside, the Federal Reserves amounting in 1945 to about 180,000,000 acres or over 280,000 square miles, more than twice the area of England, Scotland, Wales and Ireland put together, and about twice the area of Japan. Nor does this include the large areas set aside as State Forests by the individual States. With a staff of experts a federal Forest Service has been established of which the country may well be proud. A large majority of the States have in addition their own Forest Service.

Another reason for the tardiness in forest-tree breeding appears to be the discouragingly long periods of time between generations of trees. Breeding of corn, tulips, marigolds, *etc.*, where one or more generations can be raised in a single year, is far easier because striking results can be obtained in short order.

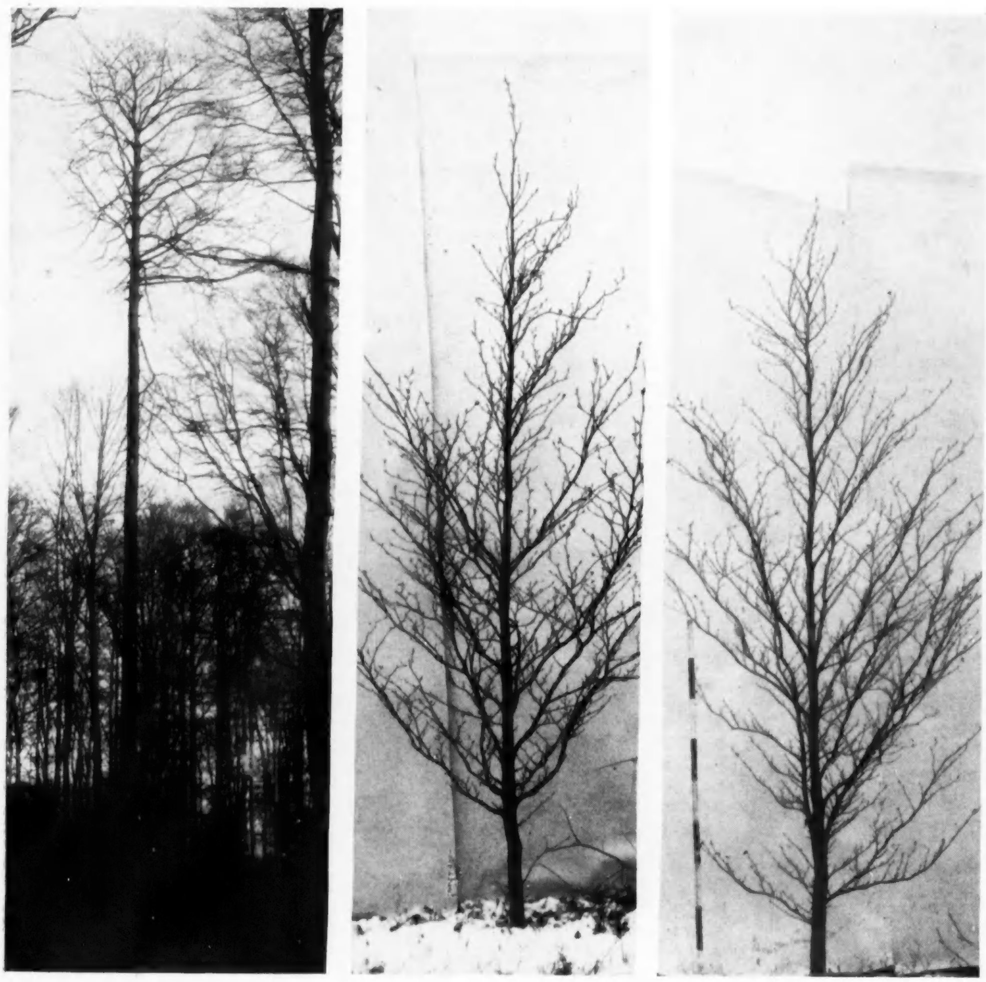
But this means only that large scale forest-tree breeding should start at once, for the view is untenable that because results are slowly achieved, tree breeding is impracticable. We must stop measuring everything in terms of the length of human life. Most forest trees are characteristically long-lived, and therefore it is fitting that tree breeding become a function of permanent institutions such as the Federal and State governments, State experiment stations, universities, privately endowed foundations, *etc.* Only thus can sustained progress be assured. Finally it should be noted that new methods of hastening generations, *i.e.*, of bringing trees more quickly to the flowering period, as well as new methods of asexual or vegetative propagation are being discovered and developed. The facts stated above, that the value of wood is continually increasing and that we are cutting it faster than it is growing, are additional reasons for the breeding and improvement of forest trees.

Methods

Selection. That breeding of edible fruits by selection has been carried on

by man and other animals for long ages has been noted. This process has been a kind of unconscious or involuntary selection and of course belongs strictly under the heading of "natural selection". The dissemination and improvement of fruits after this manner has usually been accomplished through seed distribution, and since the formation of a seed involves more than one parent, this kind of selection was characterized by repeated "trial and error". The results that have been attained therefore cover a long period of time.

Obviously such a method has not been applied to the breeding of forest trees. But long before now foresters, especially some of those in Europe where timber is scarcer and more valuable than in this country, have realized the importance of selection. The place of origin and even the mother tree was



a b c

FIG. 2. Beech, *Fagus sylvatica*, Denmark. a. Original tree. Photo Nov. 18, 1937. b & c. Grafts of 1938. Photo Jan., 1947. From "Estimation of the Genotype". *Courtesy C. Syrach Larsen.*

deemed of such importance that the term "provenience" or "provenance" has come into general use, especially in Europe, to designate the source of tree seeds. For example, it is well known that in this country many mature specimens of the Scotch Pine (*Pinus sylvestris*) are ill-formed, slow-growing, branchy trees. These defects are doubtless, at least in part, due to the provenience of the seed.

In Europe the selection of valuable tree types or even individuals for provenience has been carried on for many years. Dr. C. Syrach Larsen of the Arboretum at Charlottenlund near Copenhagen, Denmark, is a leading authority in this subject, and in his article "The Employment of Species, Types and Individuals in Forestry", published in the Yearbook for 1937 of the Royal Veterinary and Agricultural College in Copenhagen, he has outlined the history and provenience of some of the well known better types of European forest trees. Three cases may be mentioned here:

1. Dutch Oaks. These trees, selected strains of the English oak (*Quercus Robur*), are well known among European foresters by reason of their superior form and growth rate. In them we have an example of a kind of selection which has been going on for centuries, for only "heisters", *i.e.*, large husky plants several times transplanted, have been employed. Planted along certain avenues in Holland, for example, along Middachter Avenue near Arnhem, their tall straight shafts make a striking picture. Acorns from specially selected Dutch Oaks are much in demand by European foresters. The original source of the acorns for these Dutch or "Avenue" Oaks seems to have been western Germany or the north of France, but the present trees evidently represent generations of selection and are a notable illustration of this method of breeding.

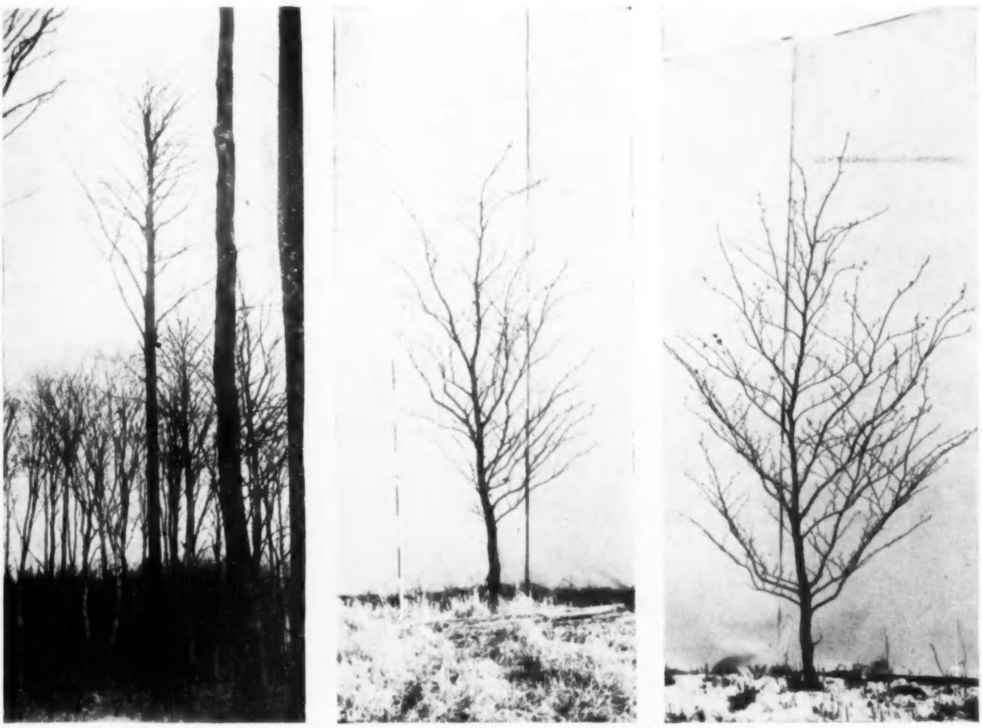
2. Dunkeld Larches. It is recorded that the European Larch (*Larix decidua*) was cultivated in English gardens as early as 1635. Specimens were taken to Scotland in 1738 and planted at Dunkeld Church, where one was still alive in 1937. These trees were the parents of the so-called Dunkeld or Scots Larch. They became the "mother trees" so often referred to in the literature, from which, as far back as 1750, seed was gathered for more than 1,000 larches planted at Dunkeld and the neighboring estate of Blair-Atholl. This bearing of seed and planting continued until in 1829 Dunkeld and several others of the Duke of Atholl's estates—about 24 square miles—were forested by this larch. Thus the so-called Scots or Dunkeld Larches are in all probability derived from a few superior trees.

3. Scone Douglas Spruces. Another type of great value in European forestry can be traced back to the Scone Douglas Spruces which developed from seed sent to Scotland by David Douglas in 1825 or 1826 from Fort Vancouver or its immediate neighborhood. This shipment was the source of the oldest Douglas Spruces in Europe and gave rise at first to the beautiful trees in Lynedoch woods at Scone, Scotland. In 1926, according to Larsen, the circumference of one of these trees about three feet above the ground was fifteen and a quarter feet. These Scone Douglases seem to be the ancestors of all the oldest Douglas Spruces in Europe, certainly of those which date back before 1877.

It is evident that in the above examples we are dealing with genotypes, not phenotypes. In the pure Mendelian sense these terms mean, respectively, the genetic constitution of an individual, that is, the hereditary factors it contains; and the obvious external characters. In the latter case the dominance of certain characters hides the others. A tree may be phenotypically tall, and

yet it may in its heredity contain the characteristic of dwarfness which has been suppressed in the inheritance or, as we say, is "recessive". The term "phenotype" has been extended by some authors to refer to the external appearance no matter to what causes that appearance is due. We do not object to this extension of the meaning; rather it is a convenient way of expressing differences due perhaps to environmental causes.

In this connection I should like to call attention to an important paper recently published by Dr. Larsen, entitled "The Estimation of the Genotype in Forest Trees". In this he describes a method by which the forester can determine whether a given vigorous and well shaped tree is a genotype or a phenotype. This is done by grafting cuttings from the tree in question on a series of uniform stocks. Fig. 2 shows at the left a fine European Beech with two young trees at the right (b and c) which have been formed by grafting scions of the old tree on beech stocks. The grafts were grown under uniform conditions on uniform stocks. The form of these new trees is proof of a good heredity in the "mother" tree. There is a definite erect leader without tendency to forking, and the branches are not unduly heavy. In the tree in Fig. 3, however, it is clear that the fine phenotype is "chiefly a result of professional treatment". The trees developing from the scions are of irregular weak growth



a b c

FIG. 3. Beech, *Fagus sylvatica*, Denmark. a. Original tree. Photo Nov. 18, 1937. b & c. Grafts of 1938. Photo Jan., 1947. From "Estimation of the Genotype". *Courtesy C. Syrach Larsen.*

and without definite leaders. It is evident that the genotype is not good and therefore not desirable for breeding. Fig. 4 shows the same situation as in Fig. 3 but in an even more striking manner. In Fig. 5 a good genotype is again apparent, as in Fig. 2. Larsen says of this last experiment, "the number of graftings is so great that their uniform appearance becomes particularly evident, all being of an excellent type, thus proving the good phenotype of the mother tree to be largely dependent on hereditary qualities".

a b c

FIG. 4. Beech, *Fagus sylvatica*, Denmark. a. Original tree. Photo Mar. 22, 1944. b & c. Grafts of 1938. Photo Jan., 1947. From "Estimation of the Genotype". *Courtesy C. Syrach Larsen.*

The object of all this work is to determine whether or not the individual tree selected is the result of superior germ plasm or of superior environmental conditions. As Larsen convincingly shows, a tree with splendid growth and habit may be only an expression of favorable external conditions. The inner nature of the tree, the genotype, may be quite inferior. Where a tree is to be reproduced vegetatively to form a clone, which by our definition is a kind of breeding, this matter of genotype is of fundamental importance.

In our chestnut breeding work it has been evident for many years that the phyllotaxy of the one-year old seedlings is an indication of the future habit of the tree. A $\frac{1}{2}$ phyllotaxy, where the leaves are in two ranks on the stem,

produces a leaning habit with tendency to forking; but a 2/5 phyllotaxy, where the leaves are disposed radially in five ranks about the stem, produces in later life a straight bole without pronounced forking. Such a relation has been followed for more than ten years and so far at least has proved true. Our ability to predict the form of the future chestnut tree from evidence presented by very young seedlings has no connection with Dr. Larsen's method of determining phenotype and genotype; it is cited here only as proof of the statement that the young stage of a tree is an index of its mature form, or, as we say, "The child is the father of the man", a thesis which has been denied by at least one writer.

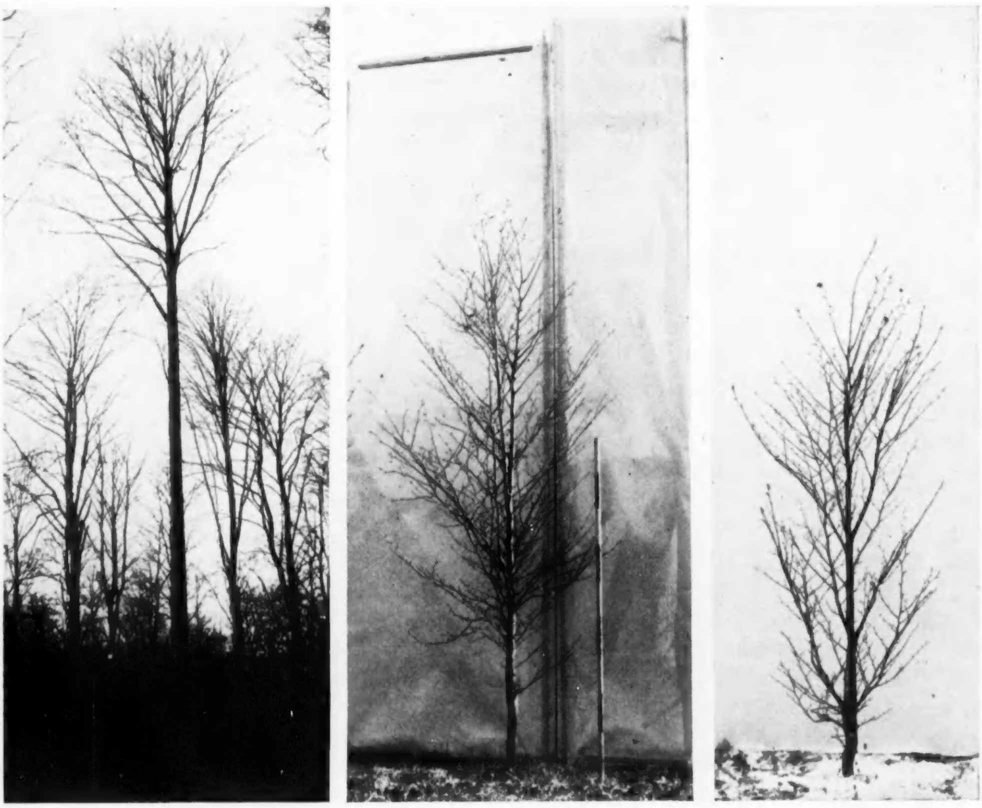


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FIG. 5. Beech, *Fagus sylvatica*, Denmark. a. Original tree. Photo Nov. 18, 1937. b & c. Grafts of 1938. Photo Jan., 1937. From "Estimation of the Genotype". *Courtesy C. Syrach Larsen.*

Hybridization. This kind of breeding, which has been called "generative breeding", means the bringing together of male and female sexual cells for the purpose of reproduction, the new individual containing then a combination of the qualities of both parents, a process essentially similar to that of animal breeding. We can have hybrids between individuals of the same species, a process sometimes called "cross-breeding", between individuals of different species, "interspecific hybrids", or even of dif-

ferent but closely related genera, "intergeneric hybrids".

All trees have flowers, for a tree is nothing more than a woody flowering plant; and in the flowers the sexual organs and cells are produced. The stamens, which we may for our purposes call the "male organs", bear the pollen, the yellow dust which consists of tiny spheres called "pollen grains". The pistils, or, in the cone-bearing trees the ovule-bearing scales, may be called the "female organs"; they bear the ovules, *i.e.*, unfertilized seeds, and each ovule contains an egg cell[3].

When pollen is transferred from the stamens to the pistil, or, more exactly, to the stigma at the tip of the latter, the pistil is said to be "pollinated". In the cone-bearing trees it is the young cones or "female flowers" that are pollinated. Transfer of pollen is accomplished in nature by wind, insects, or in some aquatic plants by currents of water.

Under normal conditions the pollen grains germinate on the stigma, that is, each grain grows a tiny tube through which are transported, among other things, male nuclei, one of which fuses with the egg nucleus in an ovule. The result is the fertilized egg. Theoretically this contains equal contributions from both male and female parents, and therefore the embryo into which it subsequently develops by growth and cell-division contains the characters of both male and female parents. Without going further into technical details, this is briefly what happens when flowers are said to be hybridized or "crossed"[4].

The young tree resulting from further growth of the embryo from the planted seed, although it contains within itself the characters of both parents, may resemble outwardly one parent only, in which case that parent is said to be "dominant", and the other parent "recessive". Or a mixture of the characters of both parents may appear, and then the dominance is said to be "mixed". Or some of the characters of one parent may appear, but the majority of the characters are traceable to the other parent,. and then the dominance of the latter parent is said to be "incomplete".

Technique of Hybridization. As we have said above, this is the same in principle as in animal breeding. The hybridizer chooses the parents and brings about their union or, rather, the union of their sexual cells. Both the method —the "know-how", to use a word now popular,—and the correct timing are important.

The first essential is to isolate the male and female parts of the flower, *i.e.*, stamens and pistils, before they have quite arrived at sexual maturity, so that when the actual crossing is done, one can be certain that the female has not already been fertilized and that the pollen is pure, that is, with no foreign pollen intermixed. Therefore, a few days before the pollen is to be shed, the flower or flowering branch bearing it is enclosed in a bag tied snugly at the mouth around the branch in order to exclude the visits of insects which might import foreign pollen on their bodies, or to shut out currents of pollen-laden

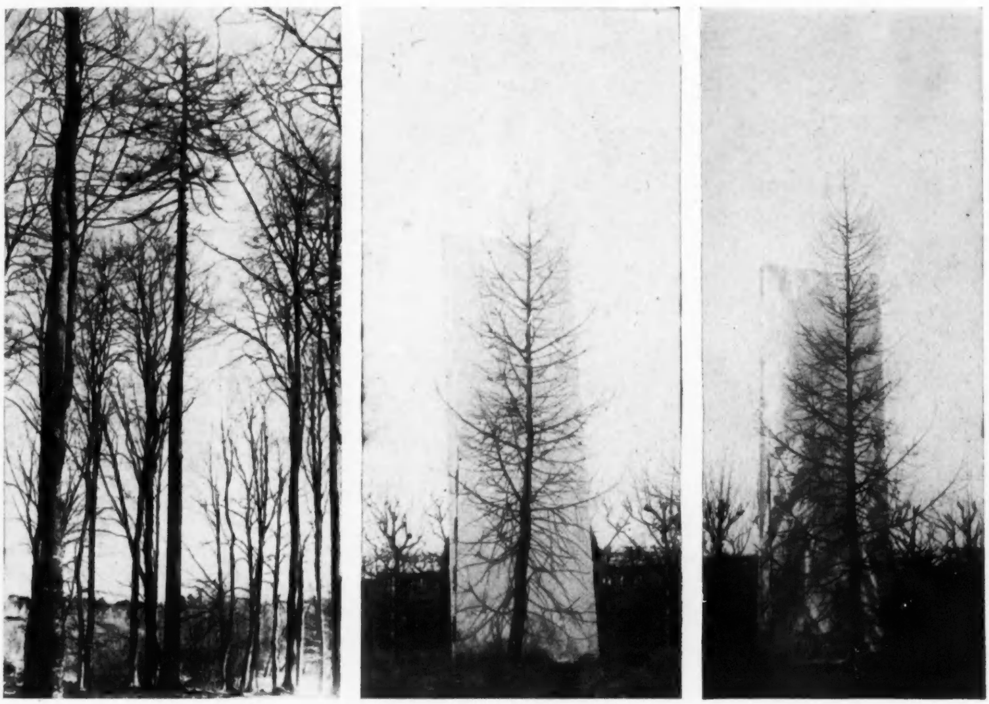
[3] Strictly the stamens and pistils have no sex. They bear the small spores (pollen) and the large spores (in the ovules), respectively, in an asexual manner. These are therefore asexual spores. And yet, since the pollen and large spores give rise in their further development to the male and female germ cells, the stamens and pistils are often, in a retrogressive sense, called the "male and female organs".

[4] We are assuming, of course, that the pollen comes from another plant. Indeed many plants are not ordinarily fertilized by their own pollen and are called therefore "self sterile". On the other hand, the pistils of some plants, *e.g.*, violet and pea, are fertilized in nature by the pollen from their own particular flower (self fertile).

air. In this operation one can entirely disregard the pistils. If they are present and their ovules become pollinated, they only furnish evidence that the flowers are self fertile, that is, can be fertilized with their own pollen.

If the flowers on the tree are perfect, as in the magnolia or catalpa, that is, pistils and stamens are borne in the same flower, the stamens are now removed from flowers on the other chosen parent, leaving only the pistils which are then enclosed in a snugly tied bag as in the manner above described for the stamens. For tying the bags we have used in our chestnut breeding work short pieces of fine copper wire. This comes in circular rolls which are easily cut into the desired length. We use common grocers' bags, size 10 or 12. Glassine or cellophane bags are also in use, but we have found the paper bags simpler, and if carefully used the chances of error are slight. Manila paper admits enough light so that the flowers and even the leaves are uninjured.

The time of bagging is important. The flowers must not be bagged too long before sexual maturity, *i.e.*, before shedding of the pollen and receptivity of the pistils. If bagging is done too early, very hot or even very cold weather may intervene before the critical period occurs, which may weaken or kill the sexual organs. The flowers should be carefully examined each day in order to determine when the bagging and also the pollination should be done. On the other hand, the bagging should not be



a b c

FIG. 6. European Larch, *Larix decidua.* Tinghus plantation, Denmark. a. Original tree. Photo Mar., 1922. b & c. Grafts of 1937. Photo Jan., 1947. From "Estimation of the Genotype". *Courtesy C. Syrach Larsen.*

done too late, especially in the case of the pistils. If bagged after they have become receptive there are abundant chances that they have already been fertilized. And just herein lies a dangerous pitfall for plant breeders, leading to alleged cases of parthenogenesis, apogamy, self fertility, *etc.* For example, if bagged pistils which were not artificially pollinated bear fruit it is sometimes assumed that the eggs have developed into embryos without fertilization. It is far more likely that they were bagged too late and had already been pollinated when enclosed in the bag. In such cases, indeed, the resulting plant tells the story, giving evidence of its parentage by its form and development.

Many plants do not mature stamens and pistils at the same time in any given flower or on any given plant. For best results in hybridization it is important therefore to be equipped with information about their relative times of maturing before beginning the bagging.

A sticky secretion on the stigmas is usually evidence of their receptivity for pollen. This can be judged with fair accuracy by inspection with a hand lens. If one knows the flowering habits, *i.e.*, whether pistils and stamens mature at the same or different times, he can also use this knowledge to gauge the receptivity of the pistils.

One method of pollination is to puncture a hole in the bag, in this case of glassine, insert the tip of a rubber bulb

FIG. 7. (*Left*). Japanese-American hybrid chestnut 24 ft. tall, 7 years old. Photo by Louis Buhle, Oct. 1, 1938. Hamden Plantations, Conn. *Courtesy Brooklyn Botanic Garden.*

FIG. 8. (*Right*). One of best Japanese-American chestnut hybrids kept alive and thrifty by repeated inarchings. Photo by Louis Buhle, Sept. 1945. Hamden Plantations, Conn. *Courtesy Brooklyn Botanic Garden.*

dropper containing pollen and blow the pollen on the stigmas. Then the hole is covered with adhesive tape. Another method is to remove the bag entirely for an instant, rub pollen-shedding anthers on the stigma and quickly replace the bag. The latter method is the one we have used in our chestnut breeding work. It has the advantage of being much quicker, and there is little chance of error, especially with insect-pollinated plants. In order to be more certain that the pistil is receptive when pollinated, we usually repeat the pollination two or three times, at intervals of a day or two.

At the time of the first pollination, a tag of some sort is affixed to the pistillate branch, giving the name and location of the male parent. This tag remains on the branch until harvest time, and serves at that time to identify the parentage of the hybrid seed.

After the danger of pollination from other sources is over, and a reasonable time has elapsed, let us say from a week to two weeks, the bags can be removed with safety. In our chestnut breeding it is necessary to bag the nearly mature chestnut burs again about September 15 to preclude squirrel thieving and also, should the nuts drop out of the bur early, to hold them in the bag until harvesting time. For this September work, bags of strong cloth are used as a deterrent to squirrel marauders. So with hand pollinated crosses of fruit, apples, pears, grapes, *etc.*, a second bagging near harvest time is necessary in order to protect the fruit from animals.

Advantages of Hybridization. For the forester the paramount reason for crossing is to produce a more vigorous, faster growing tree which will consequently yield more saw timber in a shorter space of time. The need for improvement in this respect has already been emphasized.

In hybridization the phenomenon of hybrid vigor or "heterosis" is often apparent. This is expressed by much greater vegetative growth than was manifested by either of the parents. The reasons for it are not entirely clear; possibly it is in some measure dependent upon the pairing of genes which were present only as units in heterozygous parents. Doubtless there are other causes. Hybrid vigor does not necessarily occur when two individuals are crossed, but is likely to appear in species hybrids. For example, in our crossing of Japanese with American chestnut the resulting hybrids displayed unusually fast growth in most cases, but not in all. Figure 7 shows a Japanese-American hybrid which attained 24 feet in seven years. The ordinary growth rate of an American chestnut is one foot per year, and of Japanese chestnut somewhat less. The late Dr. Dengler of Germany reported hybrid vigor in crosses of different races of Scotch Pine, *Pinus sylvestris*, and Larsen in Denmark cites many interesting cases of hybrid vigor, for example, in the cross of the Japanese Larch, *Larix leptolepis*, and the European species, *Larix decidua*, of which he figures one tree 10 years old and about 22½ feet high.

In our crosses of chestnut, precocity of flowering seems also to be a characteristic of some hybrids. The cross of Japanese and American chestnut sometimes flowers in its third year. The usual age for flowering of Japanese chestnut is five or six years, and for American 10 to 12 years. However, very early flowering may occur rarely in some species of *Castanea*. We have had flowers on Chinese chestnut at the age of one year.

In addition to these possible advantages of hybridization one must include the distinct positive advantage that we can select the parents. Thus in our chestnut breeding we have selected oriental chestnuts which resist the blight.

as one parent, and the American species with its tall erect growth, as the other parent.

Hybridization accompanied by selection can be utilized for an increased production of resin in the pines, for the development of larger and better yields of cork, for an increased development of pulpwood for paper manufacture, for a greater yield of tannin, maple sugar, or any other forest product. It has also many potentialities for the development of trees which will resist drought and thus furnish a forest cover for hilly sections now subject to erosion. These are only a few of the many opportunities open to a tree breeder by the use of both hybridization and selection. It is reported that a famous English breeder of wheat varieties said, "Tell me the kind of wheat you want and I will breed it for you". One might equally well say, "Give me the specifications of a tree you need and I will breed it for you". In the latter case, however, considerably more time is required.

Cytogenetic Work

For best results in tree breeding, careful studies of the genetic constitution of the various hybrids should be made. This can be done by the "smear" method, a short cut as compared with the much more laborious paraffin or celloidin methods. A knowledge of the chromosome numbers in somatic and germ cells will often facilitate further hybridization as well as afford an explanation of external morphological characters or, indeed, of incompatibility of certain individuals. According to recent studies, not only the nucleus of the cell, but also the cytoplasm may have an influence on heredity.

Polyploid trees, that is, with chromosomes exceeding the normal number, are likely to possess greater vegetative vigor and variability. If such trees are found to be desirable and can not be reproduced by seed they can be multiplied by grafting or by cuttings. In such a manner a "clone" can be formed, that is, a series of trees which are, in a sense, parts of the same individual and therefore identical in their heredity. It is interesting to note that many of the more valuable varieties of apple trees in this country are triploid, that is, with one and one half times the normal or diploid number of chromosomes.

In this connection the use of colchicine for doubling the normal number of chromosomes is of importance and should be thoroughly tried out with our forest trees.

Natural Mutations and Variations. The tree breeder should be constantly on the watch for individual differences in the form of the tree; branching; times of leafing, flowering and fruiting; rate of growth, leaf form, size and color; size and abundance of fruit and seed; resistance or susceptibility to diseases and insects; in fact, any deviations from the normal characters of the species or variety. These phenomena are known to occur in nature from time to time.

Such differences may be due to external or environmental causes, as mentioned above, or they may be genetic, that is, due to changes in the genes, the determiners of hereditary characters of the individual. In the latter case they may be heritable, *i.e.*, capable of being transmitted to the offspring through the germ cells, in which case they are called "mutations".

But occasionally we find variations which are apparently due to merely local changes in the genes, that is, in the cells of some branch, leaf or bud—so called "bud sports". These variations are not transmitted through the germ cells. Thus I once found in our chestnut breeding work, a branch on which certain of the leaves were variegated.

This variation, of importance only as an ornamental feature, could be reproduced only by budding or by grafting scions from the branch in question on a compatible stock. In such a manner have arisen the clones, for example, of Weeping Beech, Cut-leaved Beech, Lombardy Poplar and some of our choice fruit trees.

Induced Mutations. R. H. Richens of the Imperial Bureau of Plant Breeding and Genetics, Cambridge, and of the Imperial Forestry Bureau, Oxford, England, says in his publication "Forest Tree Breeding and Genetics" (1945): "Several methods of inducing mutation have been studied recently. X-rays, neutrons, *a*-particles, *b*-particles, chemical agents and temperature shocks have all been tried with some success. Few of the methods, however, have been applied to practical breeding problems since most of the mutations obtained have appeared to be disadvantageous. At present, then, these techniques remain of theoretical importance only, but there is reason to believe that further investigations may lead to practical applications of some importance".

Some Results

Let us now consider some of the more recent work in the breeding of forest trees, especially in this country. In most cases selection has accompanied hybridization, but occasionally, for special reasons, only selection has been used. Breeding of shade trees has for the most part not been included. This, however, is an important field of tree breeding, and work in this direction is urgently needed. The shade trees now free from serious diseases or defects of some sort are few indeed.

Breeding for Pulpwood. In the United States one of the best known tree-breeding experiments was begun in 1924 by Dr. A. B. Stout of the New York Botanical Garden and Dr. Ernst J. Schreiner, now of the Northeastern Forest Experiment Station, Philadelphia, Penna. They carried on extensive breeding of poplar, the primary object being the production of more valuable stock from the standpoint of growth as well as quality of pulpwood. Secondary objects were hardiness (resistance to cold) and comparative immunity to various poplar diseases. The work was sponsored by the Oxford Paper Company of Rumford, Maine, in cooperation with the New York Botanical Garden. Dr. Schreiner reports (Yearbook of U. S. Dept. Agr., 1937): "This work has been highly successful. A total of 13,000 hybrid seedlings was obtained from about 100 different cross combinations between 34 different species, varieties and hybrids of poplars. The parents included 3 white poplars, 5 aspens, 17 black poplars and cottonwoods and 9 balsam poplars or hybrids belonging in this group. Many of the new hybrids appear especially promising because they surpass the older hybrids, at least during the first 8 years of their life, in rate of growth, resistance to disease and climatic conditions, and habit of growth". And elsewhere he says (Paper Trade Journal, Feb. 21, 1935): "The results obtained in the poplar breeding project fully support the view that hybridization and selective breeding of forest trees will give results comparable to those realized in the development of the older crop plants". (Fig. 11.)

Unfortunately for the continuance of this poplar-breeding project, techniques were developed for utilizing for paper pulp the plentiful supply of other hardwoods available to the Company. They therefore decided not to continue with extensive plantings of poplar. However, the almost spectacular results that had already been obtained by Drs. Schreiner and Stout furnish one more striking illustration of the rich rewards that lie in wait for the tree breeder.

The Northeastern Forest Experiment Station reports (Tree Genetics News Letter **1**: 5. 1948) that its genetics project "is the direct descendant of the poplar breeding project of the Oxford Paper Company, . . . and of the Northeastern Forest Experiment Station which was maintained at New Haven, Connecticut, prior to 1942". Breeding work is being carried on with pines, mostly with the White Pine group, spruce, fir, maple, oak, ash and a few minor groups. "Emphasis is placed on the introduction of interspecific hybridizations for data on inheritance. . . . The many thousands of pedigreed progeny produced before the war are currently under test on plantations near Rumford, Maine; State College, Penna.; and Beltsville, Maryland".

Work at the Institute of Forest Genetics. Formerly known as the Eddy Tree Breeding Station, founded in 1925 at Placerville, Calif., this organization has since 1935 been sponsored by the Federal Government and is now a branch of the California Forest and Range Experiment Station, cooperating with the University of California. Extensive tests at the Institute include 100 species and named varieties of pine and innumerable climatic forms. Even with apparently the same heredity, seedlings vary greatly under identical environmental conditions. Seed of pine and other conifers has been collected from

FIG. 9. (*Left*). Seven-year-old seedling of the promising hybrid between *Pinus Strobus*, the common Northern White Pine, and *P. Griffithi*, the Himalayan or Bhotan Pine, developed at the Arnold Arboretum. *Courtesy Arnold Arboretum.*

FIG. 10. (*Right*). Showing method of inarching basal shoots of blighted Japanese-American hybrid. Note dead area at base of trunk. Photo by Louis Buhle, Oct. 27, 1942. Hamden Plantations, Conn. *Courtesy Brooklyn Botanic Garden.*

many foreign countries as well as the U. S., and seedlings are being grown for the purpose of selecting the best types for breeding.

An interesting cross has been made between Knobcone Pine, *Pinus attenuata,* and Monterey Pine, *P. radiata,* two closely related species with contiguous ranges. The hybrid has shown vigorous growth—61.7 feet in 16 years—but it is significant that this growth rate is even less than that of some Monterey Pines growing near the Arboretum. Natural hybrids between the two species occur at the borderlines of their distribution. These facts and others indicate that the genetic relationship of the two species is rather close. In reporting the situation, Drs. Stockwell and Righter suspect that commonly recognized species of today may in many instances "conform closely to the subspecies of present-day thinking". Experimental evidence of this sort is important from a taxonomic point of view.

N. T. Mirov, Silviculturist, and W. C. Cumming, Forester, of the Institute have conducted experiments to determine whether Cork Oak, *Quercus Suber,* can not be grafted on the native California oaks. Their preliminary tests indicate that such grafting is perfectly feasible. The Cork Oak is an evergreen oak and is a native of the Mediterranean region. Curiously enough, in these experiments it was found incompatible with the common California Live Oak, *Q. agrifolia.* Grafting was entirely successful, however, on the Canyon Live Oak, *Q. chrysolepis,* and fairly successful (71%) on the California Black Oak, *Q. Kelloggii,* a deciduous species. The grafting method of establishing a stand of cork oaks is promising, since scions could then be selected from trees producing the best grade of cork. Moreover, it has been found that the fast growth of grafted scions produces cork of uniform structure. For further information about cork production in California the reader is referred to Volume 1, pp. 26–46 of this magazine.

Most of the world's supply of commercial turpentine is obtained from three species of pine: *Pinus palustris,* the Longleaf Pine, *P. caribaea,* the Slash Pine, both American species, and *P. Pinaster,* the French Maritime Pine or Cluster Pine. When the resin of the pine is distilled, the volatile product is turpentine, and the solid residue is known as "rosin". Both of these are valuable commercial substances: turpentine of particular value in the paint industry; and rosin of use in the manufacture of sealing wax, soap, varnish, glaze of paper, *etc.* N. T. Mirov of the Institute of Forest Genetics has investigated the chemical composition of turpentines in these and other species of pine. He finds that each pine species, as a whole, contains a specific turpentine by which the species can be easily identified. His work suggests the possibility of crossing particular species of pine for the purpose of obtaining a larger and better yield of turpentine. Dr. Mirov says: "The pattern of occurrence of different chemical compounds in the turpentines will be a definite aid to the taxonomist who must delineate phylogenetic relationships in the genus *Pinus.* An accurate knowledge of relationships is the best guide possible in selecting the crossings to be tried among the many thousands that are possible. Thus the geneticist profits from the work of the taxonomist, who draws his conclusions from the findings of the biochemist, an excellent example of the value of coordinated effort by men of different training".

Experiments in Florida, begun in 1941, under the jurisdiction of the Southern Forest Experiment Station, U. S. Forest Service, have for their object the breeding of better resin-bearing pines. Rooting of cuttings from selected slash and long leaf pines has been successfully accomplished. Crosses between

slash pine and long leaf or some other good resin-yielding species may contain desirable characters of both parents.

Work of the Arnold Arboretum. Dr. Karl Sax, Director, writes as follows (Tree Genetics News Letter **1**: 6. 1948): "In 1937 the Maria Moors Cabot Foundation was established for the primary purpose of producing more rapid growth in trees. It was decided to carry on the breeding work at the Arnold Arboretum where there is an excellent collection of forest tree species. The nursery work is carried on at the Bussey Institution, and the field tests will be done at the Arboretum's Case Estate in Weston and at the Harvard Forest in Petersham, Mass. The early breeding work has been done by Dr. Sax and his graduate student assistants.

"The most promising parental species for producing hybrid vigor in poplars have been *P. Maximowiczii, P. deltoides, P. Koreana, P. trichocarpa, P. nigra* and the natural species hybrids, *P. generosa, P. Berolinensis* and *P. robusta.* About 75 clonal lines of F_1 hybrids or hybrid segregates have been selected for field trials after preliminary tests in the nursery plots.

"Crosses between pine species have given promising results in the white pine group. The F_1 hybrids between *P. Strobus* and *P. monticola* are vigorous, as are the hybrids of *P. Strobus* and *P. Griffithi* (Fig. 9). The *P. Strobus* × *P. parviflora* hybrids have the *parviflora* growth habit and are not likely to produce good timber trees. However, second generation segregates may be of value and may carry some resistance to insect and disease infection. Since we have found no practical method of vegetative reproduction in pines, we have planted groups of F_1 hybrid trees in semi-isolated plots in the Arnold Arboretum for the production of F_2 segregates. As Righter has suggested, the F_2 may give enough segregates with hybrid vigor to provide permanent trees in a forest plantation.

"Crosses between the American elm and Asiatic species have not been successful. We had hoped to produce such a hybrid which might be resistant to the Dutch elm disease. Crosses between *Ulmus japonica* and *U. Wilsoni* have produced vigorous hybrids which are resistant to the elm leaf beetle and presumably are resistant to the Dutch elm disease, since both parents are of Asiatic origin.

"The F_1 hybrids of *Acer rubrum* × *A. saccharinum* are far more vigorous than the red maple parent, although probably not as rapid growers as the silver maple".

Breeding for Disease Resistance. The term "disease resistant" has been much misunderstood. It is a relative term. One tree may be only a little resistant, and another very much so, and in this way variations may occur up to complete immunity, on the one hand, or complete susceptibility, on the other. With reference to disease the term is used just as with environmental conditions, for when we say "drought resistant", "cold resistant", *etc.*, we do not mean complete immunity from these dangers—only a greater ability than normal to withstand their destructive effects.

As to the causes of disease resistance, much has been written. Without going very deeply into the question we may say that even such a variation as a slightly thicker epidermis may prevent the germ tube of a fungus spore from entering the plant. Or the cell sap of a plant may vary in the direction of greater acidity, or of greater concentration, too strong for the fungus to live, or at least to thrive, in it. Or some substances may be present in the living cell matter or protoplasm which are, so-to-speak, distasteful to the fungus, and therefore, inhibit its growth. Or certain growth substances, essential to fungus development, may be lacking.

FIG. 11. Seven-year-old hybrid poplar (*Populus balsamifera virginiana* $\times$ *P. trichocarpa*) on a plantation with $6' \times 6'$ spacing in western Maine. Diameter 4.5′ above ground: 6.5″; height: 32′. (*U. S. Forest Service*).

These and other characters obviously can be the result of natural variation, and this is one reason why we may encounter variation in disease resistance among the individuals of a species.

The investigations outlined below are selected from a considerable number going forward in this country. Just as for those described above, available space limits those that can be mentioned.

White Pine Blister Rust. This is a fungous disease which has threatened the very existence of our species of the white pine group, a group which includes some of our most valuable timber trees. The fungus is a native of Europe and was imported into this country about the beginning of the present century, apparently on seedlings of our native White Pine which had been raised for the trade in European nurseries. The fungus leads a double life, so-to-speak, a sort of Dr. Jekyll and Mr. Hyde existence, with the difference that both of its lives are of a sinister nature. Thus after living on the branches and trunk of the White Pine, which in most cases it eventually kills, the fungus, by means of its spores, goes to some species of *Ribes*, either currant or gooseberry. There it attacks the leaves, on which it produces two other kinds of spores, one of which can again infect the White Pine. This dual existence has proved to be the weak point of the fungus, for to prevent the spread of the disease among pines it is necessary only to eradicate all species of *Ribes* for a distance of about one half mile from the pines. The spores borne on the pine will not reinfect the pines; they attack only species of *Ribes*. Unfortunately it is often not a simple matter to thus eradicate the currants or gooseberries, so that some authorities state that the further planting of White Pine may have to be abandoned.

But there is another possible solution of the problem and one which appears promising. This is being worked out at the New York State College of Forestry by Dr. Ray R. Hirt and his assistants. It is based on the principle of variation mentioned above. These investigators have found that certain individuals of the White Pine resist the attacks of the fungus. Dr. Hirt writes (in correspondence): "In my plantations I have discovered several trees that had severe trunk infection at 4 years of age. These particular trees are now about 20 years old and the infection entirely healed. These trees have been exposed to infection each year for 6 years. They pick up branch infections but immediately overcome them. The trees are being multiplied by cuttings and by grafts, which will be exposed to infection. . . . I have one young pine tree that has been exposed to rust infection every year for about 10 years. Although the controls died long ago from multiple infections, this tree has never had a canker. This year I expect to get cuttings from it so as to increase the stock".

Dr. A. J. Riker and associates at the University of Wisconsin have tackled the problem from essentially the same angle but on a much larger scale. They have made about 1,000 grafts and have grown 10,000 seedlings from open pollinations from selected White Pine trees in Wisconsin which, although exposed to blister rust infection for years, have remained uninfected. A large percentage of the grafts resisted infection in their nursery, while a much smaller percentage of the seedlings reacted thus favorably—which was to be expected, since the latter are the result of promiscuous pollinations, presumably from a large admixture of susceptible stock. Dr. Riker therefore concludes that vegetative propagation by grafting and by rooted cuttings is promising enough to deserve further study aimed at improvement.

Phloem Necrosis. The Dutch Elm disease is not the only trouble threatening our American Elms. In 1938 Roger

V. Swingle published (Phytopathology **28**: 757–759) an account of a mysterious disease which had long been present in American Elms in the central and lower Ohio River watersheds. In Chillicothe, Ohio, 1,000 trees, 50% of the city's elms, died in 1936 and 1937. Leaves drooped, became yellow and dropped throughout the crown of the tree. There was no discoloration of wood as in the Dutch Elm disease. "In fairly advanced stages of the disease the roots die, the small fibrous ones first. Typical discoloration, confined to phloem and cambium, precedes death of larger roots and may be found frequently extending into trunk and branches. In large trees this discoloration usually is found in large roots and at base of trunk, just before death. The cambium first becomes light yellow or golden. The phloem becomes yellow in region adjacent to cambium, then brown, with small, scattered, black flecks. Soon thereafter, phloem becomes dark brown and necrotic. An odor resembling wintergreen characterizes moderately discolored phloem".

After thorough investigation Swingle could find no fungus responsible for the disease and concluded that the trouble is due to a virus. Selection and generative breeding for resistance to this disease as well as to the Dutch Elm disease are being carried on by Swingle who writes (Correspondence of Oct., 1947): "Investigations on resistance to elm phloem necrosis were undertaken in 1940, mainly by selection for resistance among open-pollinated stock collected from an area where elm phloem necrosis has occurred for over 50 years. From this work we have obtained about 2000 trees that are highly resistant to elm phloem necrosis. These trees have not yet been tested for resistance to Dutch Elm disease. Their first inoculation with *C. ulmi* is scheduled for this coming spring. At the same time we have carried on rather small scale hybridizing experiments, mainly between *Ulmus pumila* and other elm species. Our ultimate goal has been to obtain a good shade tree type elm resistant to both of these diseases. *Ulmus pumila* has been used consistently in our controlled crosses since it is resistant to both elm phloem necrosis and the Dutch Elm disease. Our first attempts were to obtain *U. pumila-U. americana* hybrids. We failed, however, to obtain fertile seed, possibly due to *U. americana* having twice the chromosome number of *U. pumila*. Later crosses were attempted with good success between *Ulmus pumila* and *U. fulva*, the latter as the pollen source. These hybrids are now undergoing tests for resistance to elm phloem necrosis and will be inoculated with the Dutch elm disease fungus next spring. Some of the hybrids have good leaf size and color but bark and wood have the softness of *Ulmus pumila*. This season we made crosses between *Ulmus pumila* and a special strain of *U. thomasii* which has a "pin oak type" of growth and excellent wood properties. From possibly a thousand attempted crosses we have three seedlings which appear to be good hybrids as far as we can tell from their juvenile growth characteristics. These will not be of sufficient size for resistance tests until 1949.

"Our work next season and subsequent years will be mainly on selection for an American elm with combined Dutch elm-phloem necrosis resistance with the program supplemented on a small scale by controlled crosses for resistant hybrids."

Mimosa Wilt. Albizzia julibrissin, commonly known as the "Mimosa Tree", is a popular street tree in many cities of the southeastern United States. Twelve years ago a wilt, caused by the fungus *Fusarium oxysporum* f. *perniciosum*, attacked this tree, and this disease has spread so that it is now known in 82 counties in six states from Maryland to Alabama. At Morganton, North Carolina, where the wilt appeared on

one city block in 1943, trees were dead or dying on 232 blocks by 1947. Drs. G. H. Hepting and E. Richard Toole of the Division of Forest Pathology, U. S. Dept. Agr., have 632 seedlings from seed selected from Maryland to Louisiana. "After several inoculations, the remaining seedlings were planted in infested soil. Twenty of them have remained wilt-free for 5 years, while neighboring volunteers have died. Eight stem cuttings rooted from these trees and 17 from some random volunteers were inoculated at one time. All volunteer cuttings died of wilt the first year, but none of the cuttings from the resistant selections died. Rooted cuttings from trees selected at random from other locations have also proved to be susceptible. Thus, certain individual mimosa trees appear to be wilt resistant" (Phytopathology **38**: 13. 1948).

Chestnut Blight. By 1930 the fungus inducing the chestnut blight, an importation from Asia, had wiped out practically all merchantable trees of *C. dentata,* the chestnut native in the eastern United States and one of our most valuable forest trees. The Division of Forest Pathology, U. S. Dept. Agr., began breeding for blight resistance in 1926. Their program is now in charge of Mr. G. F. Gravatt and Mr. R. B. Clapper. Gravatt writes: "Several thousand hybrids have been produced, using varieties and strains of Chinese and Japanese chestnuts, the henryi chinkapin and seguin chestnut, both of China, also the American chestnut and the several species of native chinkapins. The principle objects of breeding are to obtain forest types of hybrids and hybrids as food source for game. Some hybrids and selections are being tested for nut production. Various strains and varieties of Chinese chestnut are being investigated for suitability for forest plantings. Most important results are: (1) Some Chinese chestnuts show promise as forest trees when growing under favorable situations; (2) Some first-generation hybrids of Chinese and American show promise as fast-growing forest trees with sufficient blight resistance when grown under favorable conditions. Back crossing to secure more resistance is being continued. The plantations consist of the following:

"Bell and Beltsville, Maryland. About 7 acres in chestnut selections and hybrids at Bell, and 4 acres at Beltsville.

"Chico, California. U. S. Plant Introduction Garden. Testing strains of Chinese chestnut for nut quality and cropping ability. About 2 acres.

"Savannah, Georgia, U. S. Plant Introduction Garden. Testing strains of Chinese chestnut for nut quality, resistance to seed decay; progeny testing of selected trees for orchard and forest plantings. About 2 acres.

"To these could be added our limited plantings at Fairhope, Ala., and at Athens, Ga. Trees have been distributed to the number of several hundred thousand, and therefore plantings are located all over the country where chestnuts might grow. We have a couple of nice forest plantings near Asheville on the Bent Creek Forest Experiment Station area. Dr. J. D. Diller has a large number of experimental forest plantings".

With the sponsorship of the Brooklyn Botanic Garden the present writer began breeding for blight resistance in 1930. The Asiatic species—*Castanea crenata,* the Japanese chestnut, and *C. mollissima,* the Chinese—were known to be disease resistant but unfortunately are comparatively low-growing trees and therefore not equal to the American species for timber production. Our plan was to cross the American with the Japanese species, Chinese being not available at that time, and thus combine in the hybrids the tall erect growth of the American species with the blight resistance of the Japanese. But without exception all Japanese-American crosses showed

dominance of the American parent (Fig. 7). Realizing that further breeding would produce the desired combinations, we developed a method of grafting the young suckers which appeared below the blight lesions into the living tissue above the lesions, at the same time cutting out all blighted tissue and painting the wound (Figs. 8 & 10). In this way we have been able to keep our best Japanese-American hybrids alive and vigorous to date and to continue breeding with them. We have a considerable number of Chinese × Japanese-American hybrids, dating from 1937, which so far have resisted the blight and in many cases have the erect tall habit of the American grandparent. They are promising as stock from which to develop a race for reforestation of chestnut. The work is being continued along the following lines:

1. Continued breeding for disease resistance and timber form.
2. Breeding for improved qualities of nuts and fruitfulness.
3. Search for disease-resistant individuals within the natural range of the chestnut and reproduction of these individuals on our plantation by grafting.
4. Planting of all nuts received of native chestnut on the chance that they may contain blight-resistant characters.
5. Laboratory investigations on the nature and causes of blight resistance.
6. Cytogenetic studies of the species and hybrids.

In our plantations at Hamden, Conn., and elsewhere we have about 2,500 trees varying in height from a few inches to 35 feet and comprising about 1,500 hybrids representing more than 50 combinations and nearly every species of chestnut in the world. The Connecticut Agricultural Experiment Station has now taken over the sponsorship of the work. Cooperating agencies are the Connecticut Geological and Natural History Survey and the Division of Forest Pathology, U. S. Dept. Agr.

Besides the work in Denmark, referred to above, some of the more important tree breeding work going on abroad is as follows (Tree Genetics News Letter I (1). Jan. 1948):

Sweden. Holger Jensen, Ramlosa Plantskola, Halsingborg, writes: "The principal breeding work going on in my nursery is intended, after selection from all forest trees important for our country, through grafting to propagate real elite trees, selected and approved by our forestry authorities. These grafted trees will be planted in seed producing plantations in order to make a considerable production of high class seed possible. The smallest number of elite clones for one plantation has been fixed to six, but in several cases it has been possible to select up to twelve such elite clones of the same species and climatic race. Thus far nearly 300 elite clones are being propagated. The work is done in collaboration with Prof. Bertil Lindquist of Skogshogskolan (Forestry Academy), Stockholm, and comprises the following tree species: *Pinus silvestris* (of 10 different climatic races), *Picea excelsa* (of 6 different climatic races), *Betula verrucosa* and *pubescens* of different races and wood types, *Larix europaea, sibirica, leptolepis, koreensis, kurilensis,* and *occidentalis, Pseudotsuga taxifolia, Quercus pedunculata, Fraxinus excelsior, Alnus glutinosa*".

Italy. Dr. Aldo Pavari, Director, Stazione Sperimentale di Selvicoltura, Via delle Cascine 1, Firenze, writes that in addition to general silvicultural research, his station is engaged in the following lines of work: introduction of exotic trees; hybridization (especially chestnut and poplars); genetic researches on the races of silver fir, Scotch pine, European larch. Prof. Pavari visited the United States in the summer and autumn of 1946 to study the chestnut blight, and later Spain for the same purpose.

The Common Guava—*A Neglected Fruit With a Promising Future*

This tropical American fruit, cultivated in Florida and elsewhere around the world, was used, because of its high vitamin-C content, to fortify military food rations in World War II.

GEO. D. RUEHLE
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Introduction

THE common guava, *Psidium guajava* L., belongs to the Myrtaceae which includes many aromatic plants of economic value. Well known spices, such as clove, cinnamon, allspice and nutmeg, also belong to the Myrtle family, as well as such ornamental shrubs and trees as *Myrtus, Callistemon, Melaleuca* and *Eucalyptus.* In addition to the common guava, the number of Myrtaceous species producing edible fruits is quite large, including strawberry guava (*Psidium cattleianum* Sabine), pará guava (*Britoa acida* Berg.), pitanga (*Eugenia uniflora* L.), grumichama (*E. dombeyi* Skeels), pitomba (*E. luschnathiana* Berg.), rose-apple (*E. jambos* L.), feijoa (*Feijoa sellowiana* Berg.), jaboticaba (*Myrciaria cauliflora* Berg.), jambolan (*Syzygium cumini* Skeels.) and downy myrtle (*Rhodomyrtus tomentosa* Wight).

The Myrtaceous fruit-bearing trees and shrubs are an interesting and varied group offering definite possibilities for future development of excellent fruits through plant breeding and selection. The common guava appears to offer the best possibility for such development in the immediate future.

Distribution

The common guava is indigenous to the American tropics but has been distributed to practically all tropical and subtropical areas throughout the world. In many of these areas it has become naturalized, occurring as a semiwild or wild plant.

In southern Florida the guava is commonly seen growing in uncultivated lands, about old abandoned homesteads, along drainage ditches and roads, and as a weed pest in pastures and in groves of other fruit trees. It is also reported as a weed pest in Hawaii, Cuba and elsewhere. Wilson Popenoe, in "New Crops for the New World," terms it "The Ubiquitous Guava" and continues with, "This is the ugly duckling of its tribe. The bush is so common throughout tropical America as to be a weed in many places, and it takes a very courageous soul to go into ecstasies over the merits of the fruit".

The Spanish chronicler, Gonzalo Fernandez de Oviedo y Valdez, who was in Haiti at intervals from 1514 to 1557, wrote the first account of the guava in 1526. He called it the "guayabo" (Historia general y natural de las Indias, ed. of 1851, I, p. 304) and its fruit "guayabo apple". He reported that it was common in many parts of the Indies, but better in some than in others, and that it was planted by the Indians.

Since its existence was first reported, it has traveled around the world. Evidently the Spaniards carried the tree across the Pacific to the Philippine Is-

lands at an early date, because in those islands the name "guayabos" or "bayabos" has been thoroughly established for many years. The plant likewise reached India at an early date. It has since spread to Malaya, South Africa, the Orient, Hawaii, southern California, parts of the Mediterranean and elsewhere.

The guava very quickly becomes naturalized in a climate that is suitable. Birds and other animals scatter its seeds which are numerous and retain their germinative power for a considerable time. Although the species thrives under neglect, it generally deteriorates steadily into a very inferior fruit, and by harboring fruit-flies and other insect pests it may become a serious menace to the successful culture of other fruits.

Description

If allowed to grow unmolested, the guava becomes a large arborescent shrub or small tree, branching rather freely close to the ground. It can be trained readily by judicious pruning to grow as a rather handsome symmetrical low-headed tree with a spreading top. Trained thus in orchard plantings, where growing conditions are favorable, the tree may reach the height of 30 feet with an equal spread. The trunk usually is rather slender and crooked with a greenish brown scaly bark.

The leaves are opposite, light green in color, oblong-elliptic to oval in outline, three to six inches in length, and finely pubescent below, with the veins prominently impressed above and raised below. The white flowers are borne in the axils of leaves on the four-angled branchlets of recent growth, either singly or two and three together on slender peduncles.

The fruit from seedling guavas grown from unselected seed may exhibit a wide variation in appearance, size, flavor, acidity, texture and color. The shape may be round to oblong, ovate, globose or pyriform, and weights vary from an ounce to more than one pound. Skin color of ripe fruit ranges from green to bright yellow, and in some types a faint pinkish blush occurs on the exposed side. The flesh color may be white, yellow, pink, salmon or carmine. Seedling fruits vary from thin-shelled with a large mass of seeds embedded in a firm soft pulp, to thick-shelled with few seeds, and in flavor from sweet to highly acid. The distinctive characteristic aroma and flavor of guava is possessed to some degree by all types, but in some it is very mild and pleasant, whereas others are so strongly pungent that the penetrating odor of the ripe fresh fruit is objectionable to many people.

Uses

The guava is often referred to as the apple of the tropics and deservedly so, because it serves so many uses. It has long been a staple fruit there and is becoming more widely appreciated in regions where it has been established in comparatively recent years. Once one becomes accustomed to its penetrating odor, which is dissipated by cooking, one readily acquires a taste for the many delicious culinary preparations made from the common sour guavas, and some of the better mild sweet guavas merit acquaintance as fresh fruit.

The guava is used in many ways, as fresh fruit served with cream and sugar for dessert and shortcake, or combined with other fruits in cocktails and salads. In Hawaii guava juice is said to make an excellent substitute for orange or tomato juice in child feeding. Guavas may be canned, preserved, spiced or made into jam, butter, marmalades, relishes, catsups and chutneys. The juice may be used for punch. The thick-shelled types make good pie stock, deep-dish pie or cobbler being an excellent dessert.

The greatest commercial use of the

FIG. 1 (*Upper*). Ripe fruit on the ground ready for gathering into field boxes, Miami Fruit Industries at Opalocka. FIG. 2 (*Lower*). Hauling the harvested fruit to the extraction plant, Miami Frúit Industries orchard at Opalocka.

fruit is for jelly. The common sour guava is highly desirable for jelly-making because of its distinctive flavor and high pectin and acid content. Jelly can be made from sweet varieties of guava, too, but it is of inferior quality, and it is necessary to add acid and even some pectin to make an acceptable product. Guava jelly, when made properly, is deep wine colored, clear and of rather firm consistency.

A confection called "guava paste" is made by evaporating the pulp of the whole guava until it is very thick. It is manufactured in Florida and the West Indies. A somewhat similar product is made and sold extensively in Brazil.

A wider use of guava fruit in the diet is justified on the basis of its nutritional value. Analyses of the fruit in Hawaii show it to be a good source of iron and a fair source of calcium and phosphorus, although four-fifths of the iron is said to be in the seeds and, therefore, not utilizable.

The guava is rated as a fair source of vitamin A, and analyses by various workers in Hawaii, California, Florida, Australia and India in recent years all show the fruit to be an excellent source of ascorbic acid. All varieties are rich in vitamin C, but some contain much higher quantities than others. At the Florida Experiment Station, values ranging from as low as 23.1 to as high as 486 milligrams of ascorbic acid per 100 grams of fresh fruit were obtained from the varieties under cultivation. The better varieties commonly eaten as fresh fruit contain from two to five times the vitamin C content of fresh orange juice. Somewhat higher values have been reported elsewhere.

The discovery of the high vitamin C content of the common guava, coupled with military demands for cheap sources of vitamin C to be used to fortify rations used by Allied armed forces during World War II, brought the guava into worldwide prominence and guava products into wider use. Guava puree was added to berries, grapes, cherries and other fruit products prepared for army consumption. This was done mainly to raise the vitamin C level of these products, but improvement in flavor of the companion fruit was observed from the addition of guava in some combinations. Allied troops were supplied with guava products in emergency rations as an aid in maintaining health and resistance to infections. A highly concentrated and stable powdered form of vitamin C may be prepared from guava by dehydration. It is estimated that four ounces of this powder would protect an arctic explorer from scurvy for almost three months.

A new dehydrated guava juice powder has been developed recently at the Hawaii Experiment Station. The new powder is largely pectin but is said to retain the aroma and flavor of the fresh fruit and 60 percent of its vitamin C. Since it retains the jelling properties of the original fruit and can be shipped economically to distant markets in a convenient and stable form, it should prove a useful product both in the home and in processing plants.

Guavas freeze exceptionally well, the frozen product being practically indistinguishable from the fresh fruit. With the increase in numbers of commercial lockers and home freezer units, this offers an excellent way of extending the guava season in guava-producing areas.

Guava wood is useful as fuel and is said to make excellent charcoal. It is grayish-brown, moderately hard and even grained, and is used for making various small articles.

Burkill, in "A Dictionary of the Economic Products of the Malay Peninsula" 1935, states: "The leaves are

FIG. 3 (*Upper*). Fruits of common guavas, the large one on the right being one of the new hybrids resulting from a cross between Supreme and Ruby, the others typical of cultivated guavas of unimproved types. FIG. 4 (*Lower*). Algal spotting on leaves and fruit of Redland guava. This is a common disease on some varieties of guava growing in the humid coastal areas of southern Florida; other varieties are resistant. It may be controlled by using copper fungicides.

medicinal, and are reliable enough to have been admitted into a Dutch colonial pharmacopoeia, and for an extract to have been on the market for diarrhoea and gastro-enteritis". He also mentions the use of leaves in tanning and in other minor medicinal preparations.

Guava Processing

Guava products are now manufactured in many countries of the world, but accurate figures of production and of the monetary value of the products are not available. Large quantities of the jelly were made in India, Cuba and Florida before World War II, and the manufacture of other products from the fruit has been stimulated by war needs.

The American Tropical Products Company has a large processing plant at Colon in Matanzas Province, Cuba, which is largely American owned and operated. In 1944 the plant is reported to have shipped 250,000 pounds of concentrated jelly base, and three million pounds of other guava products. In addition to this, some eight to ten million pounds of guava products were processed in other Cuban plants. In 1945 Cuba exported an estimated 6,000 short tons of guava products. Wild guava plants were the source of fruit for all this production. In 1944 the wild guava supply in Cuba was estimated at 200 million pounds. During the war factories were established to process guavas in Mexico, British Guiana and other tropical countries where the supply of wild guava fruit was plentiful.

The Processing Industry in Florida

Commercial guava processing in Florida is still a small industry. It suffered a minor setback during the war as a result of sugar rationing, but now that sugar is again available in unrestricted quantities, the industry is rapidly reaching pre-war size and is expected to surpass it.

Guava jelly is manufactured and sold by a considerable number of small plants scattered throughout the State. At one time as many as 27 were in operation on at least a part-time basis. Most of the output is now manufactured in some half dozen factories with as many more smaller concerns processing some guavas. Practically all these places manufacture other fruit products, such as citrus marmalades and tropical fruit candies, as well as guava products. The output of many of the smaller plants is sold largely within the State to tourists or local residents. Much of the output of the larger concerns is shipped out of the State.

No accurate figures are available to cover the total output from the State. One of the largest plants visited in the vicinity of Miami has a rated capacity of 10,000 pounds of guava jelly per day, but has never operated at full capacity and does not operate continuously in the manufacture of guava jelly. Several plants visited have a somewhat smaller capacity but a larger annual output of jelly.

Several of the larger concerns harvest the fruit from their own orchards or supervise the harvest from wild trees or from cultivated trees belonging to individuals. The methods employed in harvesting are quite simple. One large grower at Punta Gorda states that from 25 to 50 percent of his crop is picked directly from the trees and the balance picked up from the ground. Others shake the tree vigorously to drop the ripe fruit and harvest all the crop from the ground. The fruits are tossed into boxes or baskets with little attempt to avoid bruising, and hauled directly to the factory.

The first step in the commercial processing of the fruit for jelly consists of washing and sorting, followed by cooking. The usual method of cooking is to lower steam coils into caldrons or vats

filled with fruit for from 35 minutes to one hour. The cooked fruit is then passed through hydraulic presses. In filling the presses, the fruit is first drained through a press cloth, leaving the solid parts to be squeezed. Approximately 80 percent of the juice in the fresh fruit is recovered by this process.

Procedure differs somewhat in the further processing and storing of the juice in the different plants visited. In one plant the juice is pumped into steam-jacketed kettles where it is concentrated into a heavy syrup by driving off much of the water. In another the juice from the press is pasteurized at 200° F. In either case the juice is next placed in two-gallon or five-gallon glass jars or bottles and sealed air-tight. These are stored, often for many months, until ready for use in making the jelly. Enough juice may be extracted in a few months to run the plant for an entire year. It is not unusual for some plants to store 40 or 50 thousand gallons of juice.

The press cake from the presses is usually discarded, although it is sometimes used for mulching trees. Used in this way it undoubtedly has some fertilizer value.

Most of the plants in Florida manufacture a standard 45–55 fruit jelly, which may be labeled "Pure" on the basis of Federal Standards. This formula calls for 45 parts by weight of a 7.6 degrees Brix juice and 55 parts by weight of sugar. Small amounts of commercial pectin and citric acid may be added to make up deficiencies in the juice. The jelly usually is cooked in small batches. The usual batch contains 100 pounds of sugar and 82 pounds or 14 gallons of juice and will yield approximately 151 pounds of jelly. The batches are cooked in steam-jacketed kettles to the proper consistency and filtered before going to a filling machine in order to remove fruit particles or impurities introduced with the sugar. The jelly is then dispensed into glass or tin containers which are sealed, washed and labeled. Glasses of several types and styles are used, but most of the jelly is now sold in a 12-ounce vacuum packed glass with a metal top.

Considerable hand labor is involved in most of the steps followed in making guava jelly. Constant inspection is practiced in the plants visited, and every effort is made to turn out a uniform product.

Guavas are also manufactured commercially in Florida plants into guava preserves, guava paste, canned fruit and syrup. Guava syrup is made like the jelly, but the juice and sugar mixture is cooked to a very thin consistency.

Guava preserves are the fruit shells after the seed pulp has been removed, usually processed in a very heavy syrup. Thick-shelled and sweet guavas are usually used for this product. The fruits are more carefully harvested than the common jelly guavas and are peeled by passing them through a hot lye solution. They are then washed several times, halved, and the seeds removed before processing in syrup.

Canned guavas are the whole fruit, peeled and halved but cooked in a light sugar syrup.

Guava paste is made of the pulp of the whole fruit with the seeds removed, cooked with equal weight of sugar added. It is usually cooked to a very firm consistency and must be sliced to serve. Guava marmalade and guava butter are products made in the same manner but are cooked to thinner consistency and are used as spreads.

Orchard Development in Florida

Guavas were first planted commercially in Florida about 1912 in an orchard of several hundred trees at

Palma Sola. The trees were seedlings, and some 10 or 12 more or less distinct types were recognizable. The trees were frozen to the ground in 1917, but suckered from the base and were again producing fruit in 1919. Although this grove contained nothing but seedling trees originally, all of the poorer fruiting trees have been top-worked by grafting to good producers. When visited recently, many of the original trees were found to be thrifty and heavily laden with fruit, 35 years after planting. Many vacancies were also observed where trees had died out in past years.

Several other old bearing guava orchards are scattered throughout southern Florida. One of the largest of these is located near Opalocka, and comprises 40 acres of guavas. The trees are pruned up to a uniform height from the ground, and a Bermuda-grass sod is maintained as ground cover for the light sandy soil in which the trees are growing.

When the orchard was first observed by the writer in 1943 the trees were in rather poor condition because of lack of proper nutrition. Increasing the quantity of mixed fertilizer over what had been applied and spraying the foliage with a zinc sulfate spray rapidly brought about considerable improvement. Although the trees were damaged some by a hurricane in 1945, the orchard produced 235 bushels of fruit per acre or 47,000 gallons of juice in 1946. The orchard was sold to the Miami Fruit Industries, Inc., a fruit processing concern, a few years ago at a reported price of $40,000.00.

Guava orchards have been planted in recent years at Palma Sola, Punta Gorda and Indiantown. New plantings are being established this year at these and at other points in the State, and trees are being grown this year for planting new orchards in 1948. It is estimated that the orchards planted to guavas in the State now total more than 400 acres, and if the present trend continues, this figure may well double within a few years.

The increased interest in the establishment of guava orchards in recent years has prompted the Florida Agricultural Experiment Station to study the soil and cultural requirements of the guava, to investigate methods of propagation, and to try to develop better varieties by selection and breeding. While worthwhile accomplishments have been made, much more research is necessary if the guava is to be raised to the position it so richly deserves in both commercial and home plantings.

Soil and Climatic Requirements

The common guava is not particular as to soil. In Florida it thrives on well-drained loamy and muck soils but succeeds almost equally well on sandy flatwoods soils that are too wet for the successful culture of avocados or citrus fruits. It will thrive on very acid (pH 4.5 to 5.0) light sands or on moderately alkaline (pH 7.6 to 8.2) limestone and marl soils if properly fertilized. It thrives on the red clay soils of Cuba and can be grown on adobe soils in California.

Writers in India report that the guava prefers a rather dry climate, yet it produces heavy crops in southern Florida where the annual rainfall varies from 45 to more than 70 inches. Heavy and prolonged rains at the time the fruit is ripening may cause considerable skin cracking followed by spoilage. It has been observed also that considerable raininess during the period of blossoming tends to reduce fruit setting, probably by reducing insect activity and thus decreasing chances for pollination.

Young guava plants are quite tender, sometimes being killed outright by tem-

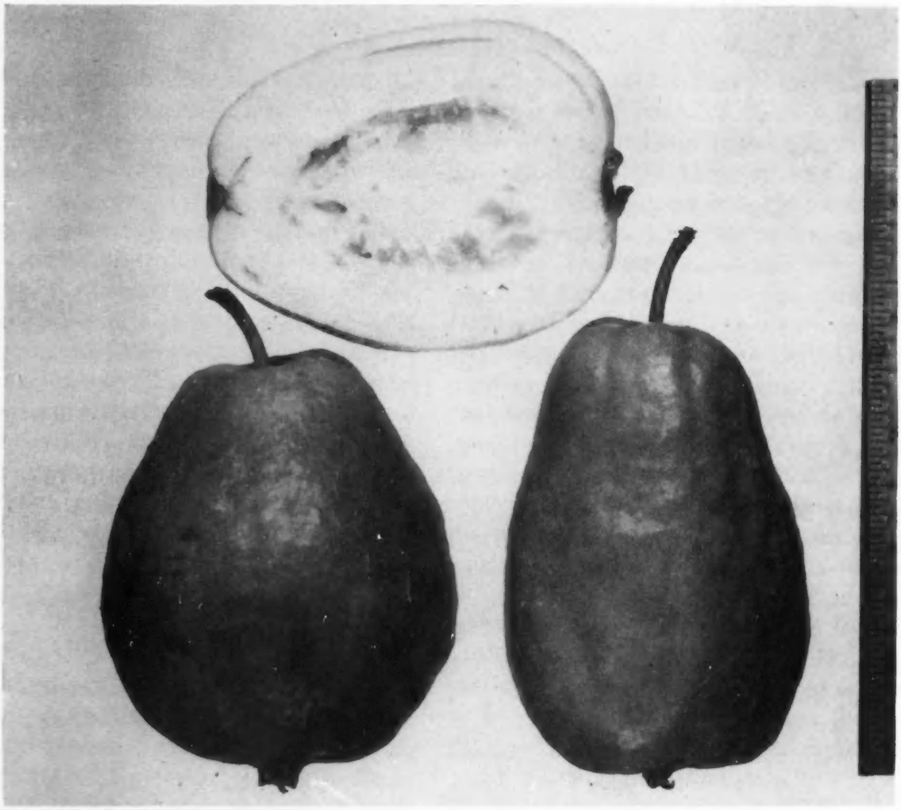


FIG. 5 (*Upper*). Supreme guava, one of the new selections made at the Florida Sub-Tropical Experiment Station. This variety produces very heavy crops of thick-shelled white-fleshed fruit of good quality. It is resistant to algal spotting and is being used as one parent of some of the crosses being made at the Florida Station. FIG. 6 (*Lower*). Hybrid guavas from Supreme X Ruby cross. Fruit on the left is red-fleshed like the female parent; fruit on the right resembles the white-fleshed male parent. Of 140 seedlings grown from seed from a single fruit, about 60% are producing red-fleshed fruit and the remainder white-fleshed. Several trees from the cross have fruit superior to the fruit of either parent.

peratures of 29° F. Mature plants have been severely injured by temperatures of 28° F., especially if they were fertilized with nitrogenous fertilizers shortly before the freeze. On the other hand, plants 18 months old from seed have withstood a temperature of 26° F. at one foot above ground level and 28.5° F. at 4 1/2 feet above ground level at the Sub-Tropical Experiment Station, with only partial defoliation and no loss of wood. These trees had been fertilized heavily from the beginning with a low analysis mixture containing nitrogen, phosphoric acid, potash and water-soluble magnesium, and have received foliage sprays containing salts of copper, zinc and manganese. When mature plants are severely frozen back, they usually recover very quickly by suckering vigorously from the uninjured wood.

Guavas are found growing in the tropics from sea level up to 5,000 feet elevation, according to Wilson Popenoe (Manual of Tropical and Subtropical Fruits, page 276, 1924). Whether the quality of the fruit is affected by altitude is not known. J. Eliot Coit (California Avocado Society Yearbook, 1945, page 42), in discussing the opportunity for commerical guava culture in California, states that the guava "requires a large number of heat units for attainment of quality", and discourages the planting of guavas in coastal areas of California where sufficient heat is lacking. In Florida cold seems to be the chief hazard to growing guavas.

Cultural Requirements and Practices

In India, where commercial guava cultivation is extensive, it is reported that the trees are commonly planted 18 to 24 feet apart. The soil is tilled occasionally, and at least once a year the trees are fertilized, mostly with barnyard manure. Irrigation is practiced during the dry season.

In the western hemisphere, in countries where wild trees furnish practically all of the fruit for processing, little or no attention is given to culture. In Florida, where the planting of guava orchards is expanding, it is apparent that the trees were set too close in the early plantings. Tree spacings of 10 to 12 feet were used in some instances. Overcrowding followed, necessitating considerable pruning to facilitate fertilizing, mowing, spraying and harvesting. Spacing of 12 to 15 feet in rows 24 feet apart have been used in more recent plantings. Indications are that in commercial orchards where heavy fertilization is to be practiced, trees should not be planted closer than 20 feet in rows 20 to 25 feet apart.

Guava trees are usually planted to best advantage during late spring or early summer just ahead of the rainy season. The land should be cleared and prepared some months before. In deep soils the land should be plowed and disked. The soil in the tree rows should be ridged or mounded if the land is low and poorly drained. Shallow limerock soils should be well scarified and grooved or plowed out where the tree rows are to be located. On newly cleared sandy soils with low pH and low levels of calcium and magnesium, it is desirable to make a general application of dolomite at 500 to 2,000 pounds per acre, the amount depending on the degree of correction necessary, broadcast and disked in just before or just after the trees are planted. An application of 600 pounds of superphosphate per acre similarly broadcast is desirable on recently scarified limestone soils.

It has long been known in Florida that guava trees respond to fertilization. Trees growing within barnyards, poultry yards and corrals, or in fence rows surrounding such enclosures are larger and produce more fruit than wild trees

FIG. 7 (*Upper*). Guava juice stored in sealed glass bottles at the extraction plant of Miami Fruit Industries at Opalocka. The juice may be stored for months in perfect condition either in the open or in storage rooms before being made into jelly. FIG. 8 (*Center*). Guava tree 15 months from seed which received a complete fertilizer containing N, P, K and water soluble magnesium plus copper, zinc and manganese applied as a spray. FIG. 9 (*Lower*). Air-layering of guava, using rubber plastic film to wrap the sphagnum. The plastic wrapper allows the escape of respiratory gases but retains sufficient moisture to keep the moss moist until roots form. Paper collars placed over the wraps prevent birds from pecking holes in the film.

of the same age growing without benefit from animal manures.

Research conducted in recent years supplemented by observations in commercial orchards in Florida has shown that the common guava responds as well to complete fertilization as do citrus fruits and the avocado. There is evidence that the guava requires more nitrogen than the orange, particularly during the periods when the fruit is sizing. There is little likelihood that the guava will be damaged by over-fertilization within reasonable limits, provided secondary element requirements are satisfied. The lack of certain of the secondary elements in the soil in which guavas are growing causes various troubles. These are manifested by symptoms characteristic for the particular deficiency present. Thus zinc deficiency is characterized by little-leaf, shortening of the internodes and chlorosis. It is corrected by applying zinc sulfate to the soil if the pH is on the acid side or by spraying a solution of the chemical on the foliage. Copper deficiency is manifested by attenuated growth, reduced leaf size and premature defoliation followed by dieback. The condition is corrected by soil applications of copper sulfate or by spraying the foliage with a copper spray. Manganese deficiency has been observed on guavas growing in marl soil and is characterized by a mottled type of chlorosis of leaves of normal size. It can be corrected with manganese sulfate applied either to the soil or to the tree as a foliage spray.

Magnesium deficiency symptoms are at present poorly defined. The general chlorosis and premature defoliation occurring in autumn on branches which bear a heavy load of fruit is considered in part as a manifestation of magnesium deficiency, since the symptoms are considerably less evident on trees receiving appreciable amounts of water-soluble magnesium with the fertilizer. Since guava seeds contain considerable iron, it is possible that a temporary iron deficiency may be responsible for a part of these symptoms accompanying heavy crop production.

Young guava trees may be grown very rapidly by the use of nutritional sprays combined with frequent and liberal applications of fertilizer. Applications to the foliage every three or four months of a nutritional spray containing copper and zinc improve the growth and vigor of seedlings growing in plant containers or in the nursery row. A spray formula suggested is cuprous oxide, 1.5 pounds; zinc sulfate, 3 pounds; hydrated lime, 1.5 pounds to 100 gallons of water.

After planting, a complete fertilizer should be applied every four to six weeks the first year and every 60 days the second year, except during the period between November 15 and January 15. The type of mixture used should be modified or supplemented according to the nature of the soil. For most Florida soils, mixtures analyzing about 4% nitrogen, 7% to 9% phosphoric acid, 3% potash and 1.5% water-soluble magnesium, with at least 30% of the nitrogen derived from natural organic sources, will satisfy most general requirements. The mixture should include 1% to 2% manganese derived from manganese sulfate for use on soils that contain marl. On muck soils the nitrogen may be eliminated or greatly reduced in the fertilizer program. The amount per application should begin with a half pound per tree and be gradually increased to one pound by the end of the first year and two to three pounds per tree by the end of the second year.

Nutritional sprays containing copper and zinc should be applied three times a year during the first two years. Feb-

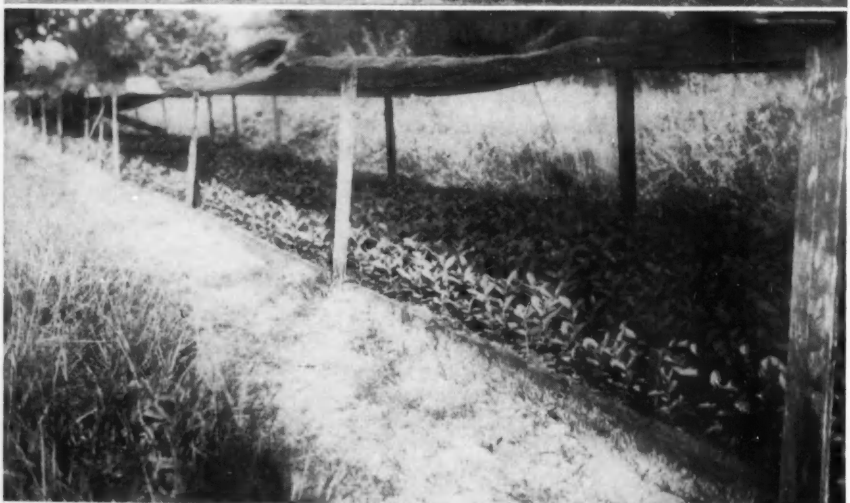


FIG. 10 (*Upper*). Portion of a 40-acre guava orchard near Punta Gorda, Florida. The trees were three years old and yielded 100 bushels of fruit per acre at this age. Most of the fruit is harvested from the tree in orchards of this age.

FIG. 11 (*Center*). Portion of a guava nursery at Punta Gorda, Florida. Seeds were started in flats and the seedlings transferred to small pots and finally to the field. Gauva trees do not transplant readily from open ground. FIG. 12 (*Lower*). Portion of a 40-acre orchard at Opa-locka, Florida, which belongs to the Miami Fruit Industries, Inc. at Hialeah, Florida. The trees are spaced about 20 ft. × 20 ft. and have been pruned to a uniform height from the ground. A Bermuda grass sod is maintained as ground cover. This grove produced 47,000 gallons of juice in 1946.

ruary, June and September are appropriate months for applying such sprays. When grown on marl soils, guavas will benefit from the addition of manganese sulfate to the sprays to supplement the MnO added to the fertilizer.

Young trees fertilized according to this program at the Sub-Tropical Experiment Station grew with exceptional vigor and produced a crop of fruit 23 months after the seed was planted. Individual trees in the block produced up to 25 pounds of fruit.

Guava trees properly fertilized may be expected to produce fruit the third year, and yields as high as 100 bushels per acre have been taken from trees of this age.

Experimental data are lacking regarding fertilizer requirements for bearing guavas growing on the diverse soil types found in southern Florida. It is evident from observations made in bearing commercial groves that fertilizer practices used successfully on citrus on the various soil types will also give satisfactory results when used on guavas. Low analysis mixtures containing 4% or 5% nitrogen, 5% to 7% phosphoric acid and 5% to 8% potash applied two or three times during the year, supplemented with applications of top dressings of nitrogen-bearing materials at times when peaks of fruit are sizing, is a practice which has given good results. The fertilizer mixtures used should contain at least 3% water-soluble magnesium and should also contain 1% MnO if they are to be used on marl soils.

Annual applications of zinc and copper supplied as nutritional sprays should be continued. In general, the higher the poundage of fertilizer applied, the greater is the need for copper and zinc. The grower can determine by observation whether more than one application of nutritional spray is needed per year, once he has become familiar with copper and zinc deficiency symptoms.

Some pruning of young trees is necessary if a desired shape of tree is to be attained. As the bearing trees become older there is a tendency for the fruit to become smaller. The largest fruit is borne on strong shoots arising from two- to three-year old wood. By moderate thinning out and heading back of the top every two or three years, the production of this type of shoot will be stimulated and large fruit may be maintained.

An ample supply of soil moisture during the fruiting season is required for maximum yield. If needed and used at this time, irrigation will increase production by increasing the size of the fruit.

Definite information is lacking concerning the best type of cultivation to be practiced in guava orchards on all soil types. On limestone soils the growing of a cover crop of native grasses or weeds which is mowed periodically, allowing the cut material to decay on the ground surface, is the most satisfactory practice. In most sand soils the practice followed in many citrus groves of allowing the cover crop of native grass and weeds or of planted legumes to grow during the summer period when rainfall is abundant should prove satisfactory. The cover is usually mowed once during the summer or chopped in with a crop chopper. Plowing and deep cultivation, whereby guava roots are cut, is undesirable because of the danger of causing root suckering.

Varieties

Only a few named horticultural varieties of guava exist at present, and trees of these are not yet offered for sale in quantity by nurserymen. The first guava variety to attract attention in Florida was the Redland, described in

1941. Fruit of this variety from young trees is very large (up to 16 ounces), firm, white fleshed, with relatively few seeds and with little of the strong odor characteristic of most of the common guavas. Subsequent study revealed that its foliage and fruit are extremely susceptible to spotting by the alga *Cephaleuros virescens* Kuntze, that the ascorbic acid content of its fruit is very low for guavas, and that fruit from older trees is quite variable in size. Since its flavor is very mild and is rated as inferior to that of fruit of some of the later selections, the Redland is no longer recommended, unless one desires an especially mild flavored guava.

Three newer selections made at the Sub-Tropical Experiment Station are superior to the Redland in quality and possess sufficient merit to be propagated for distribution by nurserymen. The Red Indian and Ruby are red fleshed, sweet, large-fruited, dessert-type guavas producing good crops of fruit of high quality. The Supreme produces very heavy crops of thick-shelled, white-fleshed fruit of good quality suitable for preserving or eating fresh. All three of these new varieties produce fruit high in ascorbic acid content and are excellent types for planting in home gardens or for sale as fresh fruit.

From the work of the late Dr. H. J. Webber in California, several named varieties of guava are now available in that State. Some of Doctor Webber's selections have been grown in Florida. Three of them have been registered as varieties with the Subtropical Fruit Committee of the California Avocado Society. The Riverside is described as a medium-large fruit with creamy yellow flesh and a good flavor and with a sugar content of 9.5%. This is the best of the California varieties which has fruited in Florida to date. It was reported in the California Avocado Society Yearbook for 1946 that the Society had authorized its Subtropical

FIG. 13. Miami Fruit Industries salesroom and factory at Hialeah, Florida. Tropical fruit candies and marmalades are manufactured in this plant as well as guava jelly.

Fruit Committee to change the name of the Riverside guava to the Webber. The Rolfs is described as a medium-sized, pink-fleshed fruit of good quality having a sugar content of about 9%. The Hart variety is described as a relatively large fruit, light yellow in color with a sugar content of about 8%. Neither the Rolfs nor the Hart appears promising in Florida.

Named varieties of guava exist in South Africa, Puerto Rico, India and elsewhere, although it is probable that many of the forms listed as varieties are seedling races rather than true horticultural varieties propagated by vegetative means. A seedless or almost seedless type has been reported in India.

Practically all of the commercial orchards in Florida are of seedling trees. Local descriptive names, such as lemon guava, pear guava or apple guava, are in use for some of the common types. Quality of the fruit, however, cannot be determined from the color, shape or size. Some processors have certain types which they prefer for the manufacturing of jelly or other products, and propagate these by planting seed from selected fruit or by grafting. Seedling guavas cannot be relied upon to produce fruit identical with that from the parent tree. Choice varieties can be increased only by some vegetative means of propagation.

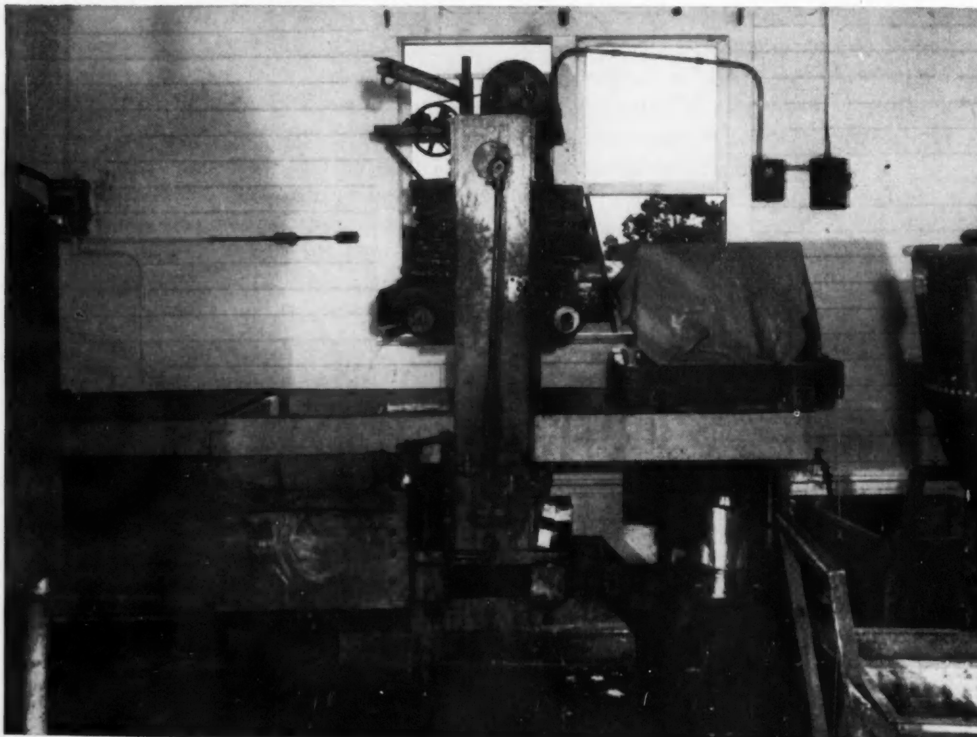
Propagation

Guavas are still commonly propagated from seed. Seeds should be sown in flats and covered to a depth of about a quarter of an inch. If the soil was not previously sterilized, it is advisable to treat the seed with red copper oxide before planting and to spray the young seedlings and soil with wettable cuprous oxide to prevent damping off. After the true leaves appear, the seedlings should be transferred to individual containers where they should be grown until they are large enough to set in the field, since they are not easily transplanted from open ground.

The guava is rather difficult to propagate by the usual vegetative methods employed with other fruits. Both shield and patch budding or side-veneer grafting are successful on young stock plants, but it is difficult to obtain a high percentage to live. Shield budding is most successful if the buds are inserted in young stocks as soon as the bark is thick enough to receive the bud. Budding is best done during the winter and early spring. Buds should be cut one to one and a half inches long from wood from which the green color has just disappeared from the bark. When older stocks are used, shield buds frequently fail to sprout readily.

Side veneer grafts on young stocks, using scion wood of the same diameter as the stock, are somewhat more difficult to make live than shield buds. However, if the union is successfully made, the graft develops into a tree faster than the shield bud.

Patch buds can be made to live on stocks an inch or more in diameter, but the buds usually start growth slowly and this method has little to recommend it. Stocks of this size are readily topworked by use of the crown bark graft similar to the method used in topworking citrus, except that it is advisable to take precautions to protect the scions from drying out. This can be accomplished by tying a paper collar around the stub and scion and filling it with moistened peat moss, sphagnum or a mixture of these materials with sand, in addition to coating all exposed cut surfaces with grafting wax. By taking similar precautions against drying out of scions, large seedling trees may be top-worked in the orchard, either by cleft or crown bark grafting. Usually, however, the guava persists in suckering below the graft union following the topworking of old trees.



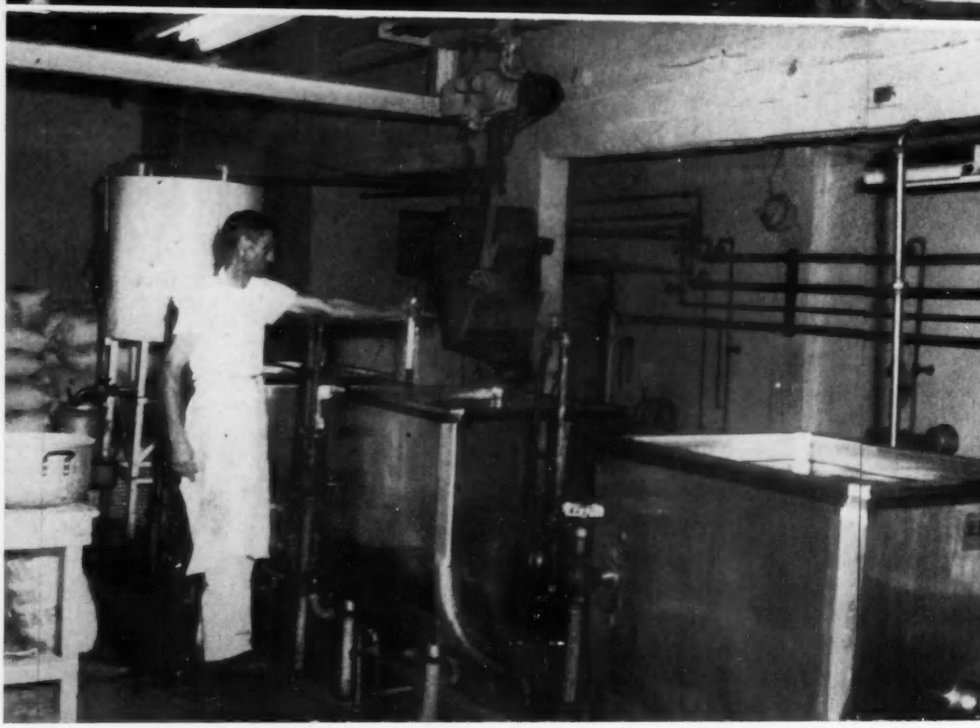


FIG. 14 (*Upper*). Press used for extracting juice from cooked guavas at Miami Fruit Industries extraction plant at Opalocka. FIG. 15 (*Lower*). Cooking guava juice and sugar mixture to jelly consi tency in steam jacketed kettles, Miami Fruit Industries, Hialeah, Florida.

If guavas are grown where there is danger of the top freezing back to the ground, it is advisable to have the roots of the same variety as the top, so that the original variety will be retained when suckers arise. The guava can be air-layered successfully by the ancient method employed by the Chinese for generations for propagating the lychee, but the expense of watering the soil or of moss used as rooting medium is a serious drawback to the method. A new method of air-layering recently developed by W. R. Grove, owner of Lychee Orchards, Laurel, Florida, for rooting lychee trees, has proved to be an excellent method for propagating the guava. Limbs of a half inch or more in diameter are girdled by removing a strip of bark about one and a half the width of the limb. The girdled area is bound with a ball of moistened sphagnum which is

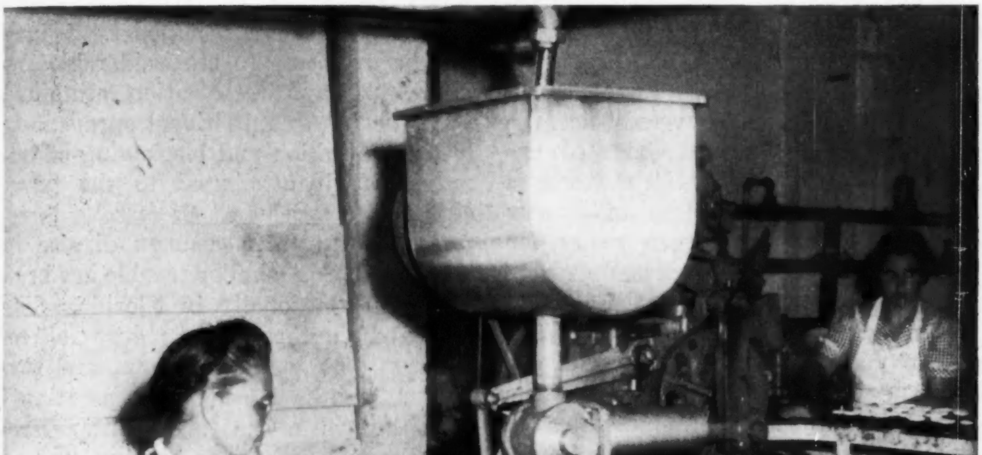


FIG. 16. Filling the glass jars with guava jelly, Miami Fruit Industries, Hialeah, Florida.

then wrapped with a sheet of heavy rubber plastic film tied securely at each end with rubber bands and left alone until sufficient roots can be observed through the plastic wrapping. The wrapper allows the passage of respiratory gases but retains sufficient moisture to keep the moss moist until the new roots form. As soon as roots fill the ball of moss the stem is severed below the wound, the plastic and most of the leaves are removed, and the new tree is planted in a shady place until new growth begins. It is then ready for planting in the field. Trees can be made in three or four months at relatively low cost by this method. The cost of material is but a few cents per tree and labor cost is low because the expense of watering is eliminated by the use of rubber plastic film.

Another method of making a limited number of plants is to sever roots two or three feet away from the trunk with a spade or mattock. Sprouts will grow from the severed portion and may be transplanted later. Root cuttings five to eight inches long cut from roots a quarter to a half inch in diameter planted horizontally to a depth of three or four inches in nurseries or cutting beds will often root with fair success, if the soil is kept moist but not too wet. Some success has also attended attempts to root stem cuttings treated with hormones. Rooting is rather slow, however, and the method is less reliable than air layering with rubber plastic film.

Diseases and Insects

The guava has its share of fungous and insect enemies, many of which have not been studied adequately.

Spotting of leaves and fruits caused by the parasitic alga, *Cephaleuros virescens* Kuntze, is rather severe on some types and varieties of guava, particularly in the humid coastal areas of Florida. Other varieties, such as Supreme, show very little spotting. Spraying with a nutritional spray containing copper and zinc reduces infection considerably.

The guava is subject to rootknot caused by parasitic nematodes. Injury can be overcome to a considerable degree by heavy fertilization combined with the use of nutritional sprays.

Mummification and blackening of immature fruit attributed to the parasitism of a species of *Glomerella* is reported as a rather common disease in Puerto Rico. A similar trouble has been observed occasionally in Florida. The ubiquitous anthracnose fungus, *Colletotrichum gloeosporioides* Penz., and several unidentified fungi are associated with decays of mature fruit. Frequently such infections are initiated at insect stings or at cracks developing in the skin after heavy rains.

Mushroom root rot caused by *Clitocybe tabescens* (Scop.) Bres. has been reported on guava in Florida, but is of minor consequence.

The guava is subject to the attacks of numerous insects. The guava white fly, *Metaleurodicus cardini* (Back), and the numerous species of scale insects attacking guava are controlled by the use of oil emulsions, as used on citrus for scale and citrus white fly control.

In recent years the larvae of a tiny moth, *Argyresthia eugeniella* Busck., have caused considerable damage at times in Florida by tunneling through the fruit. Little is known concerning the life history of this pest, and control measures have not been worked out. Small pit-like punctures through the skin of the fruit are caused by a small weevil, *Anthonomus costulatus* Suffr., and larvae of this insect are sometimes found in the flesh. Biology and control measures have not been worked out for this pest.

The red-banded thrip, *Selenothrips rubocinctus* (Giard.), is sometimes troublesome on the guava, causing defoliation and fruit russetting when the infestation is heavy. Spraying with nicotine sulfate 1–800 or with rotenone and derris-resinate sprays will effectively control this pest.

Plant bugs occasionally sting the fruit, sucking juices from the flesh. The stung areas usually decay as the fruit ripens. While satisfactory measures have not been developed for control, some of the new insecticides under test show considerable promise for control.

Other insects of lesser importance attacking guavas in Florida are the cotton or melon aphid, *Aphis gossypii* Glov., a species of broad mite, one or more species of leaf roller or leaf tier and a lepidopteran leaf miner.

In many tropical countries fruit-flies cause serious trouble and constitute one of the most serious obstacles to improvement of the guava in those countries. Florida is fortunate to be free from the more dangerous pests of this type.

Research

The Florida Sub-Tropical Experiment Station has been actively engaged in research on the guava for a number of years. Seeds of superior types have been and still are being imported from various parts of the world. A start has been made in the selection of superior varieties, methods of propagation are being developed and cultural requirements on various soil types are being studied. The work has been expanded in the past few years to include a study of the important insect pests attacking guavas in Florida, and to cross varieties and types to develop new ones for specific purposes.

The guava is a good subject for the plant breeder. The flowers are large and easily manipulated, and it is possible to obtain fruit in two years after the seeds from hand-pollinated fruits are planted. It should be possible in a comparatively short time for a tree crop to develop varieties possessing desirable qualities for specific uses. The first lot of hybrids of known parentage to fruit at the Sub-Tropical Experiment Station include a number of trees possessing qualities superior to either of the parents.

Research on the guava has been stimulated by the discovery of the high vitamin content of the fruit, and considerable work is now being carried on in several localities. The University of Miami at Coral Gables, Florida, is actively engaged in studying methods of processing and preserving in an effort to increase utilization of the fruit. Research to improve the guava is being conducted in South Africa, India, the West Indies and elsewhere. This augers well for the future of this fruit which is richly deserving of a high position among the tropical fruits of the world.

Growing Better Tobacco

Proper application of knowledge concerning the nutritional requirements of tobacco is an important factor in the production of better crops.

J. E. McMURTREY, JR.[1]

TOBACCO is grown commercially in certain well defined areas where the soils and climate have been found to produce the desired quality of product. The varieties grown, as well as the cultural and handling procedures (9, 11), must be adapted to give a cured leaf tobacco which is acceptable to the trade. There is possibly no other field crop grown which requires a higher degree of specialization. The small seedling requires special attention from germination to the transplanting stage. Field culture must follow the cropping system best adapted to the plant, and the fertilizers to be used require the right composition, method, rate and time of application to produce a satisfactory and profitable crop. Curing procedures vary with the type of leaf grown and should be understood by the grower to give leaf tobacco of good quality.

It has become increasingly difficult in recent years (1, 14) to produce an abundant supply of healthy tobacco seedlings for transplanting. There are many factors involved, among which is the prevalence of several diseases, notably blue mold (*Peronospora tabacina*) and sometimes bacterial leaf spots (*Phytomonas tabaci* and *P. angulata*). Due partly to these diseases and to scarcity of suitable wooded areas, seedbeds have been located, in increasing numbers, in open fields on soils which have a low moisture, fertility and organic matter content. There is usually little or no protection from chilling winds, and there is a greater potential weed hazard.

A permanent seedbed is desirable from many standpoints, for a suitable location can be provided with water and windbreaks. This type of location necessitates some form of sterilization of the soil to control weeds and diseases, and it has been found possible to maintain a bed for 30 years in the same location, using steam sterilization (13, 14) by the inverted pan method. Steaming with buried tile (1) has also given good results. Since steam boilers are not commonly available, substitute procedures have been sought, and it has been found that certain chemicals can be used for a period of five years in the same location, at least on good sandy loam soils.

These chemicals, calcium cyanamide (1, 3) and urea at 1 pound, or a combination of ½ pound of the former and 1 pound of the latter, per square yard of seedbed area, have given good control of weeds, while urea alone and in combination with the cyanamide has controlled root knot (*Heterodera marioni*) and black root rot (*Thielaviopsis basicola*). These chemicals have not always given satisfactory results on heavy soils, nor is it evident that they can be used successfully on a permanent seedbed location continuously. They are being used widely at present time on light soils on temporary sites with good results as to weed control.

Effective control of blue mold (2, 7) has been found to be possible by the use of ferric - dimethyl - dithiocarbamate (Fermate) or other materials in a syste-

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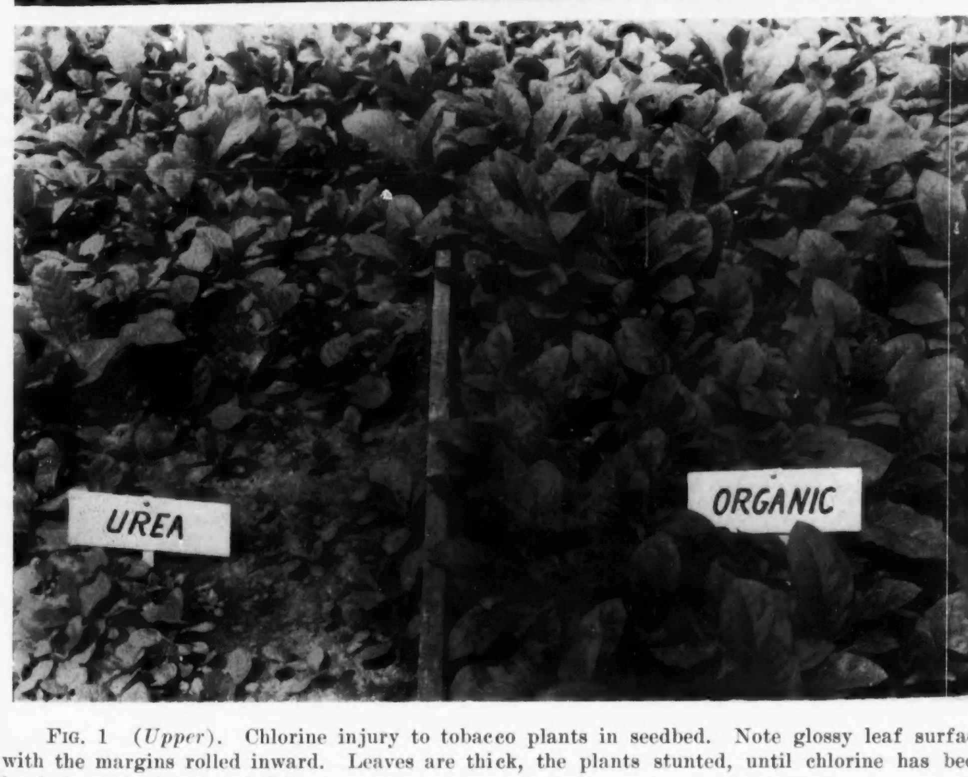

FIG. 1 (*Upper*). Chlorine injury to tobacco plants in seedbed. Note glossy leaf surface with the margins rolled inward. Leaves are thick, the plants stunted, until chlorine has been leached out by heavy rainfall.

FIG. 2 (*Lower*). Tobacco seedlings grown where two pounds of 4–8–3 fertilizer per square yard were applied prior to seeding, urea as the only source of nitrogen on the left, tankage as the source on the right.

matic spray or dusting schedule with treatment beginning prior to appearance of the disease. The gas treatment (8), using paradichlorobenzine and additional covers to retain the gas, has the advantage that the treatment can be started after the disease appears, but there is one serious handicap in that, when low temperatures prevail, the gas may not volatilize in sufficient amounts to give control of the disease. The use of a bordeaux spray applied prior to the blue mold schedule has given practical control of the bacterial leaf spot disease in the plant bed.

Liberal applications of fertilizer of varied analysis are commonly used, for example, a 4–9–3 mixture, 4 per cent nitrogen (N), 9 per cent phosphoric acid (P_2O_5) and 3 per cent potash (K_2O), may be applied at from 1 to 2 pounds per square yard of seed bed area. The potash should be derived from sources low in chlorine, since the muriate frequently brings about thickening of the leaves and stunting (Fig. 1) of the plants. It is often desirable to supply some magnesia (M_gO) in the seedbed mixture, and amounts equivalent to 5 pounds of epsom salts per 100 square yards of seedbed area have been found sufficient to take care of observed shortages of magnesia. Nitrogen should be derived from mixed sources (1) with a large proportion from (Fig. 2) organic materials. Nitrogen entirely derived from nitrate has given poor results. The phosphoric acid is usually derived from superphosphate.

Cropping Systems

Continuous cropping to tobacco has been practiced with considerable success in Connecticut where heavy rates of fertilizer applications are the general practice. This system is used also in Wisconsin. However, in most tobacco areas various diseases coupled with exhaustion of soil fertility, erosion and impaired physical condition of the soil often result in the production of leaf unsuited to market demands when continuous culture is practiced. Some form of rotation is used widely in practically all tobacco areas, but recent studies have materially improved our knowledge as to better cropping systems.

There are numerous diseases (5, 6, 11) which are more or less prevalent throughout the tobacco areas, and the damage caused by them is decidedly modified by the suitable cropping systems. Root knot is almost universally present in the light soils of the flue-cured area, and on such soils tobacco should not be grown in rotation with, and certainly not directly after, sweetpotatoes, Irish potatoes, corn, soybeans, cotton, tomatoes, lespedeza and cowpeas, since such crops usually result in the development of root knot. Practical control of root knot can be attained by growing tobacco in a 3-year rotation, using Spanish peanuts and oats or rye. Tobacco following a 2-year or longer weed cover usually gives good root knot control. When Granville wilt (*Bacterium solanacearum*) is present, tobacco should not be grown after pepper, peanuts, tomatoes, Irish potatoes or some of the common weeds. The black shank (*Phytophthora parasitica* var. *nicotianae*) disease of tobacco, when the soil is infected, may be carried by Irish potatoes, tomatoes and peppers if grown in the tobacco rotation. The prevalence of black root rot is modified to a considerable degree by the length of the rotation and the kind of crops grown. For example, root rot is usually more severe when cowpeas are used in the rotation and less severe after a well established grass sod. Soil reactions commonly brought about by the use of lime to grow certain legumes frequently increase the injury from black root rot.

Considerable progress has been made in recent years in regard to development of disease-resistant strains (4), but maintenance of soil fertility, control-

FIG. 3 (*Upper*). Tobacco following annual lespedeza (A) and weed fallow (B). Note stunting and irregularity of growth after lespedeza.

FIG. 4 (*Lower*) Tobacco showing effects of fertilizer placements, 500 pounds per acre of a 6–16–12 formula, on survival and subsequent growth. 5. Mixed with a small amount of soil around plant roots. 4. Band 3¾ inches wide, 1 inch under plant. 2. Bands 2½ inches to each side and 1 inch above root crown. 3. Bands 2½ inches to each side, 1 inch below root crown.

ling erosion and creation of necessary physical condition of the soil to obtain good tilth require a good cropping system to insure satisfactory yields of high quality leaf.

Legumes to turn under as the crop to immediately precede tobacco may be used successfully on light soils subject to leaching, but on most other soils such a system frequently supplies too much nitrogen. It is frequently necessary to grow a non-legume between the legume and tobacco. Unless Granville wilt is present, tobacco in Maryland (Fig. 3) and the flue-cured area has been observed to do well after the dominant weeds (15) found in the area, such as ragweed (*Ambrosia artemisiifolia*) and horseweed (*Leptilon canadense*). Usually these weeds grow in association with several wild legumes. The duration of the weed cover often determines the benefit derived, and two or more years yield better results than a single year. The fertility level, freedom from disease, and tilth of the soil which occurs under this system, usually result in the production of high quality leaf. Much the same has been found to be true of burley tobacco following a bluegrass sod of several years' duration. Such systems result in the production of leaf quality approaching that grown on newly cleared land. A suitable combination of cultivated crops to give a high yield of good quality leaf and a profitable return annually is much to be desired. Since overproduction of low grade leaf is an ever present threat to the tobacco grower, the above systems offer a workable solution for keeping production of tobacco within proper bounds, at the same time maintaining the quality of the product.

Fertilizer Practices

A complete fertilizer for the tobacco crop of the flue-cured type should supply rather definite amounts of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O), but in addition on many soils it should contain calcium (CaO), magnesium (MgO), sulphur (SO_3) and chlorine (Cl), approximating 3–8–10–6–2–8–2 percentages of these constituents in the order given. Most soils will require an application of such a mixture at the rate of 800 to 1,000 pounds per acre for desirable results. Excessive quantities, particularly of nitrogen and to a lesser extent of the mineral elements, are to be avoided with flue-cured tobacco.

The fertilizer application to cigar filler, cigar binder, burley, Maryland (11, 18), dark air-cured and fire-cured types should be much the same formula as regards nitrogen, phosphoric acid and potash, while the rate per acre may be around 500 pounds or less. Fertilization practices in the cigar areas of Connecticut and Florida vary somewhat from the above types where as much as two tons of 6–5–6 may be used to furnish 200 to 250 pounds of nitrogen and potash and 100 pounds of phosphoric acid per acre. Manure may be used to a greater or less extent with all these types with reductions in the fertilizer applied. Applications of chlorine should be held to a minimum with all these types of tobacco.

The tobacco plants manifest characteristic growth effects (17) when any one of the essential elements is deficient in the soil and where it is not supplied in the fertilized mixture.

The sources from which the several ingredients in the fertilizer mixture may be derived are numerous and varied. There are essentially three forms of nitrogen: nitrate, ammonia and complex organic. The nitrate is the most available form for plant growth and at the same time the most leachable. The ammonia form possibly approaches the nitrate in availability for plants but may be somewhat less subject to leaching. The complex organic forms are not immediately available to plants but are

eventually so, and in addition they are least readily lost by leaching. In order to combine the above strong points of all three forms of nitrogen under varying weather conditions, it is generally to be recommended that one-third of the total nitrogen be derived from each. Superphosphate, double or treble superphosphate and dicalcium phosphate have been found to be satisfactory sources of phosphorus (P_2O_5). The potassium (K_2O) may be derived from any available source, provided the chlorine content of the mixed fertilizer prepared does not exceed 3 per cent for flue-cured tobacco. Applications of chlorine much in excess of 20 pounds per acre have decreased the fire-holding capacity of the leaf, but since there were certain desirable effects on the growth the slight reduction in fire-holding capacity were not serious if the chlorine applications were held to not more than 25 pounds per acre. If tobacco by-products are used as a source of potassium (K_2O), these should be sterilized to kill any organisms that might be present to cause disease. The choice of the sources of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) in the fertilizer mixture should be such as to supply the required amounts of calcium, magnesium, sulphur and chlorine.

The inclusion of boron at ½ pound per acre as borax or boric acid, manganese, copper and zinc at around 1 to 2 pounds per acre as sulphates, when necessary to correct deficiencies on normal soils which are usually acid, may be expected to take care of shortages of these elements. However, on neutral or alkaline soils, these amounts will need to be increased.

The importance of the proper method of fertilizer application on survival and subsequent growth (Fig. 4) of the tobacco plant is another recent development in tobacco fertilizer of great practical significance in all tobacco regions. Applications to only one side of the plant frequently produce one-sided growth effects. Application in bands at each side of the tobacco, 1 inch below the root crown (16), have consistently produced best results as regards survival of transplants, as well as final yield and value of the crop. Delayed application of fertilizer when practiced should be as a rule not more than 21 days after transplanting.

Curing Procedures

Leaf tobacco, when harvested, contains about 80 percent water. Most of this water is lost during the curing process, and as much as 20 per cent of the dry matter. Curing is not simple drying (10, 11), since certain chemical changes take place to develop the desired qualities in the leaf. The final product depends in a large measure upon the characteristics of the leaf when harvested. The chemical changes for successful curing depend upon type of tobacco grown. There are essentially three methods of curing as practiced in the United States at this time—fire curing, flue curing and air curing.

The fire-curing procedures at the present have changed somewhat due to scarcity of fuel, with a consequence that there is less firing, and sawdust has come into quite general use as a part of the fuel. Flue curing, which appears to have been an outgrowth of the fire-curing method but which differs in that the smoke from the burning fuel is not allowed to come in contact with the leaf, is extensively used for cured bright cigarette leaf. Here also the supply of wood for curing is scarce and expensive; therefore substitutes (19) have recently been investigated. It has been found that coal stokers (20) with a capacity of 35 to 70 pounds of coal per hour, controlled by thermostat with fire control with or without combination time clock with a suitable relay, are giving satisfactory results. Sometimes the time

clock system is used alone. The smaller size apparently had sufficient capacity for the ordinary sized flue-curing barn. The use of time clock appears to be desirable to prevent the fire from going out when low temperature is necessary during the yellowing period. A furnace lined with fire brick is necessary when a coal stoker is used. Under ordinary conditions coal stokers are more economical of fuel than wood or oil, and there is less attention required from the operator during the curing. Where electricity is not available for the operation of the stoker, oil burners of the brooder type have been used with satisfactory results for curing flue-cured tobacco.

Recent studies of air curing have been made, and it has been found that relative humidity and not temperature is the critical factor in air curing. However, low temperatures are never desirable. High temperatures and high humidity will favor rapid curing, while low temperatures and low relative humidity will result in drying without proper curing. A temperature ranging from 60° or 65° to 90° or 95° F. has been found to give a satisfactory cure, provided the humidity is favorable. Cigar tobaccos have given satisfactory cures at 80 per cent relative humidity with a temperature of 90° F., while burley tobacco (12) has been reported to cure best at a relative humidity of 65 to 70 per cent.

The recent development in regard to hay curing by means of fans would appear to offer some possibilities of adaptation to air curing of tobacco. The distribution of air by means of suitable ducts and proper humidistatic controls need to be developed.

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Utilization Abstracts

Plants and Plastics. The modern plastics industry was born in 1868 when celluloid was first produced by combining cellulose nitrate with camphor. In that discovery cotton furnished the cellulose, and the camphor came from camphor trees. Since then "the use of plants or plant products as essential sources of derivatives for, or physical components of, plastics products" has expanded along with the plastics industry, and today plant cellulose and lignocellulose from many kinds of plants besides cotton are basic ingredients in the manufacture of plastics products.

Celluloid found use in billiard balls and detachable collars for men's shirts, and the modern version of this type of plastics has gone into dresser sets, tool handles, hammer heads and transparent cases for wet storage batteries. Another combination of plant materials—cellulose nitrate, castor oil and pigments—produces artificial leather. More recently other cellulose derivatives have been developed—cellulose acetate, cellulose butyrate, cellulose propionate and ethyl cellulose—each with particular properties that render them especially suitable for particular purposes, including steering wheels, instrument panel trim and laminating film in safety glass. While cellulose in the form of nitrates, acetates and butyrates has thus found wide use in plastics, hemicellulose, too, has played a part in the industry.

Another kind of plastic that has had extensive use in industry involves, not any derivative of cellulose, but the use of finely ground woodflour in a resin binder made from phenol (carbolic acid) and formaldehyde. In addition to thus finding use for sawdust from lumber mills recent research has also revealed that various agricultural residues, ground into a fine flour—corncobs, wheat straw, peanut shells, hemp hurds, flax shives—can be used for the same purposes as woodflour.

"Cellulose is composed of chains of molecules with six carbon atoms", but "hemicellulose contains pentosans, or five-carbon compounds, that may be converted to furfural by the action of dilute acids. Furfural may be reacted with phenol and other materials to produce resins suitable for plastics production, and plastics molding compounds of this type are in commercial production".

Lignin, the binding material that holds together the cellulose fibers of plant structure, may be separated from the other cell wall constituents either by being dissolved, leaving the cellulose as a fibrous residue, as is done in the manufacture of paper pulp, or by being left as a granular residue after the cellulose is dissolved by appropriate means. Such isolated lignin has possibilities for plastics manufacture, but industrial use of it as a sole binder has not yet been developed.

It has been found that by heating wood chips for a short time under high-pressure steam, and then suddenly releasing the pressure of the steam, the chips are caused to explode into a mass of fine fibers that can be molded under heat and pressure into strong, high-gloss, water-resistant sheets four feet wide and 12 feet long. "Other simple shapes such as rods and bars can be molded, but the product does not have sufficient plastic flow to produce intricate molded objects. The theory of the process is that the high-temperature steam softens the lignin bond in the wood so that when the wood explodes the fiber bundles separate at the lignin bonded surface. When these fiber bundles are molded under heat and pressure, they are welded together again through the lignin bond. The high-pressure steam treatment also converts some of the materials in the wood to water-soluble products. These products are removed in the refining process with the result that a more water-resistant product is produced".

Research along these lines has been pursued at the Forest Products Laboratory, Madison, Wisconsin; at the Agricultural By-products Laboratory, Ames, Iowa; and at the Northern Regional Laboratory, Peoria, Illinois. This work has enabled one paper mill to produce "lignin-enriched wood pulp in sheet form, which when laminated under heat and pressure produces panel board products"; another result has been that "plastics molding compounds are being produced commercially by a modified process from sugar-cane bagasse, which is the crushed, juiceless

sugar-cane waste from the sugar mill"; and experimentally a continuous process has been developed for converting a ton of corncobs into approximately 40 gallons of alcohol, 300 pounds of furfural and 300 pounds of lignin concentrate. Furfural is a colorless, oily liquid, of pleasant odor, obtained by destructive distillation not only of corncobs but also of bran sugar and wood. Industrial uses for it are already known; utilization of extracted lignin, however, still awaits much development.

The goal of all the above implied investigations is to have industrial utilization of other agricultural products emulate what is being done with flax, in which case the seeds are pressed to extract linseed oil; the extracted seed residue is used as feed; the straw is run through machines to remove the tow or outside layer which is then used for the manufacture of cigarette and other fine paper; the fibers produce linen; and the straw residue, or shives, has been shown by the Northern Regional Laboratory to be useful in making high grade plastics. (*R. V. Williamson, Jour. N. Y. Bot. Garden 47: 225. 1946*).

Vanillin from Lignin. In the manufacture of paper pulp from wood it is necessary to remove, by chemical treatment, the lignin component in the cell walls of the wood, and for many years countless tons of extracted lignin have thus been discarded as useless. Today more than 5,000 000 tons of lignin are extracted annually throughout the world, and only in recent years have uses for the material been developed.

One of those uses is in the extraction of vanillin, for which the lignin from coniferous woods, principally spruce, is employed. "Approximately 30 percent of lignin is contained in the pulp of these woods together with other major constituents such as cellulose and hemi-celluloses, which are carbohydrates or sugar-like substances. Vanillin is produced from the lignin by subjecting it to a controlled cooking and extracting process permitting its preparation in a much simpler manner than is possible by any multi-step process formerly employed in its manufacture. The final purified product is an exceptionally fine vanilla aroma and answers all of the requirements of the United States Pharmacopoeia, and is, in fact, a chemically pure product. As it comes out of the final purifying step it is a white needle crystal, chemically protocatechuic aldehyde, 3 methyl ether, chemical formula—$C_8H_8O_3$. The quality and the purity of the product thus produced is constant, and since its introduction it has assumed its place as the largest source of vanilla".

In addition to its use as a flavoring agent in confections, ice creams and baked goods, this extracted vanillin has been used to render chlorinated water tasteless and to deodorize rubber exposed to heat on magnetos or other parts of airplanes.

Veratraldehyde, the methyl ester of vanillin, has found use as a flavoring and perfuming agent, and papaverin, another by-product of the process, has sedative qualities. Other by-products range from tanning agents to plastics, and the possibilities of still other utilization conquests induced the author to conclude: "We have witnessed in our own lifetime the huge developments that arose from coal-tar and its derivatives; more recently the increasing and varied developments in cellulose. Now apparently we have a new basic raw material of great potentiality, not only in the United States, but throughout the world". (*C. K. Wellenkamp, Chemurgic Digest 5(10): 186. 1946*).

Natural Perfume Materials. This is the title of a 338-page illustrated volume published by Rheinhold Publishing Corp. in 1947 which is a translation by Edward Sagarin of "Les Parfums Naturels" by Y. R. Naves and G. Mazuyer. The French work was published in 1939, and since little research was devoted to the natural perfume industry in France during the subsequent war years, the present English version of it is regarded by the senior French author as fully up-to-date. It is divided into four parts, namely, "A Brief History of Natural Perfume Materials", "Modern Processes of Manufacture", "Chemical Composition and Analytical Examination of Products of Extraction, Enfleurage and Digestion" and "Monographs on Natural Perfumes". The discussion of each of these phases is rather extensive, and considerable chemical information is given. Most of the botanical information is in the fourth part, and the data

presented there, along with pertinent information elsewhere in the book, may be abstracted and summarized as follows. It must be born in mind that the natural perfume industry, including both extensive cultivation of the plants utilized and extraction of their perfume, is concentrated in Provence, France, about the city of Grasse, and that the statistics and description of the industry as presented in this book are based upon the activities in Provence.

The methods of isolating natural odorous products from plants fall into four categories, namely, steam distillation, digestion, enfleurage and extraction by means of volatile solvents. Steam distillation is the most frequently used, yielding essential oils, known also as essences, but it is a method which has several drawbacks, the most important of which are "the modification or the creation of odorous bodies by the chemical action of water; the difficulty of extracting odorous substances which are not volatile or which are appreciably soluble in water; and the inability to employ steam distillation for the isolation of the perfume of certain flowers, among others the jasmin. These defects and shortcomings are overcome by several other methods of extraction", and the latter are accorded primary consideration in the book. Digestion consists of immersing the plant material in melted fats or in oils heated over a water-bath to 40° to 70° C. The process of enfleurage, like that of digestion, rests upon the capacity of fatty bodies to absorb perfume, and is utilized in connection with those flowers that continue to generate perfume after they have been cut. Such flowers are kept at ordinary temperature for a day or more in contact with mixtures of lard and suet which absorb their perfume. The perfumes are then extracted by means of ethyl alcohol. Direct extraction of perfumes from the blossoms by means of volatile solvents—petroleum ether, benzene, toluene, methyl alcohol, ethyl alcohol or acetone—is the method most frequently mentioned. Selection of any method or of any solvent depends on a great many factors, and preparation and handling of the material in all methods is elaborate and variable according to the plants used and other conditions. The raw materials from which extracts are made are fresh plant matter composed of flowers, leaves and herbaceous stems; dried plant parts consisting of roots, rhizomes, wood, leaves, fruits, seeds, resins, balsams and gum-resins; plant juices and distilled waters of aromatic plants, such as orange flower water and rose water.

Among the several hundred species of plants noted in the book, the following are the most important in the perfume industry, and the figures of production in tons of flowers treated apply almost wholly to the harvests in Provence, France.

Acacia Cavenia (Leguminosae). Flowers harvested in Provence and in Algeria, mainly in the springtime until May, secondarily in October. The plants are cultivated, and annual harvests of the blossoms have varied from 20 to 30 tons before 1920 to five to eight tons before the late war.

Acacia Farnesiana (Leguminosae). The true acacia of perfumery. A thorny shrub growing spontaneously in tropical Africa, the West Indies, on the southerly spurs of the Himalayas, in Australia and New Caledonia. Cultivated for industrial extraction of its perfume in Provence, Algeria, Egypt and Syria. Propagated by seedlings. Flowers in three years. Harvest begins in late September, lasting until end of November, with less returns until January. Blossoms gathered twice weekly, one by one. Annual harvests have varied from 35 tons in 1900 to about ten tons in the 1930's.

Acacia dealbata (Leguminosae). Mimosa. Introduced from Australia and cultivated around Grasse. In some years nearly 80 tons of flowers have been treated.

Boronia megastigma (Rutaceae). A bushy plant up to six feet tall, native to western Australia. Flowers harvested from August to October, and for several years 75,000 pounds of them were annually treated in Australia.

Cananga odorata (Annonaceae). Ylang ylang. Production of the important essential oil from this tree was formerly almost entirely confined to the Philippines but has since become a monopoly of the French colonies in the Indian ocean (Comores, Nossi-Be, Madagascar and Reunion).

Cistus spp. (Cistaceae). Labdanum, Ladanum. Several species of this genus, espe-

cially *C. ladeniferus*, growing in France, Spain, Cyprus, Rhodes and other parts of the Mediterranean area are sources of second-grade extraction products. More than 150 tons were treated in Grasse in 1937.

Citrus Aurantium (Rutaceae). Bigarade, Sour orange. Blossoms are the source of néroli, or orange flower oil, and of orange flower distilled water. Prepared in Provence, Algeria, on the Italian Riviera, in Calabria, in Egypt and on Comores. Annual production of flowers in Provence has varied between 1,000 and 2,000 tons.

Dianthus Caryophyllus (Caryophyllaceae). This carnation is cultivated in the entire region of the Antibes, in Provence, and also in Holland, for sale as a cut flower. Such sales diminish after June, and the flowers are then gathered for extraction, being collected after sundown when they have the greatest amount of perfume. Annual quantities treated at Grasse have declined from some 200 tons 40 or 50 years ago to only a few tons by 1938.

Gardenia jasminoides (Rubiaceae). Cape Jasmin. Used in China, Japan and Indochina to flavor tea. *G. citriodora* and *G. devoniana* are among the aromatic species, the blossoms of which are harvested in November and December for perfumery.

Helichrysum angustifolium (Compositae). Everlasting, Immortelle, Herb of St. John. This species and *H. Stoechas*, also treated for perfumery, are widely distributed in North Africa, Portugal, Spain, Languedoc, Provence and Italy. Up to 15 tons of flowers are treated annually in Grasse. The everlasting of florist shops is *H. arenarium*.

Hyacinthus orientalis (Liliaceae). Hyacinth. Cultivated in Holland and around Grasse for cut flowers and for perfumery. From 1920 to 1928 about 75 tons of hyacinths were treated annually at Grasse. In 1926 one Dutch house treated 85 tons.

Jasminum spp. (Oleaceae). Several odorous species of jasmin, especially *J. officinalis* var. *grandiflorum, J. Sambac* and *J. auriculatum,* have long been cultivated in the neighborhood of Grasse, in Algeria, on the Italian Riviera, in Sicily, Egypt, Palestine, Syria, India and French Guiana. Cultivation of the plants and extraction of their perfume were determining factors in the development of the perfume industry about Grasse. Flowering there extends from the last of July to the first of November. Annual production figures of flowers collected have varied from 600 tons before 1913 to 1500 tons in 1927. The flowers of *J. odoratissimum* are used in Formosa, where they are known as Schuei flowers, to flavor tea, and are similarly employed, along with blossoms of *J. Sambac,* also in other parts of Asia.

Lavandula officinalis. (Labiatae). Lavender, Lavandin. Extensively extracted but tonnage figures not given.

Lilium candidum (Liliaceae). Before 1914 up to three tons of flowers were treated annually.

Michelia Champaca (Magnoliaceae). Champac. An orange-yellow-flowered tree of India, Nepal, Assam and Bengal to the foot of the Himalayas; cultivated in Java and the Philippines. The perfumed oils and fats are prepared by natives of India, Java and the Philippines. The white-flowered *M. longifolia* (= *M. alba*) and the pale yellow-flowered *M. montana* are also exploited.

Narcissus Jonquilla, N. Tazetta, N. poeticus (Amaryllidaceae). These are the principle species of jonquil and narcissus extracted for perfume. Annual production of flowers since 1919 has fallen from 30 to five tons for jonquil, and for narcissus rose from 40 to 80 tons in 1924.

Polianthes tuberosa (Liliaceae). Tuberose. Introduced into France in 16th century from Mexico. The plantations are renewed every year by changing the site, the bulbs being gathered in November and planted in April. Quantities of flowers treated annually have fallen from 75 tons immediately after World War I to 30 in 1926, 17 in 1927 and almost none thereafter.

Ribes nigrum (Saxifragaceae). Black currant. Wild in temperate regions of Europe; cultivated in France and Holland. "Its dried leaves are used as medicinal herbs, and its fresh buds and fruits are employed by the liquor industry" because of the essential oil in them.

Rosa damascena. May rose. This species, supplemented by such garden varieties as Ulrich Brunner, van Houtte and tea roses,

are the main sources of rose flower oil and oil of rose waters in France. Before 1914 the annual production of May rose in Provence reached 2,500 to 3,000 tons; after World War I it fell to 1,500 tons; by the middle nineteen thirties it was only 400 or 500 tons.

Rose bush plantations in Provence are cultivated for an average of ten years, and maximum production is in the fourth or fifth year. There is extraction also in the Balkans, on the Italian Riviera, and in Algeria, Morocco and Turkey.

Salvia Sclarea (Labiatae). Clary sage, Musky sage. Wild in North Africa and southern Europe. Cultivated for distillation at Langeudoc, in the valley of the Rhone, the Var, the Basses-Alpes and the Maritimes Alps; also in Germany, Hungary, Roumania and Russia. Only the upper extremities of the stems are used.

Spartium junceum (Papilionaceae). Spanish broom. A shrub covering large sections of the grassy mountainsides of Provence and Languedoc; cultivated in certain regions, particularly around Lodève, for the textile fibers of its stems. Extract products are among the precious raw materials of perfumery; 50 tons of the blossoms were treated in 1926, varying amounts in other years.

Syringa oblata var. *Giraldii, S. Julianae, S. pinnatifolia, S. Sweginzowii* and *S. tomentella*, all from China, have superseded *S. vulgaris* and *S. persica* as sources of lilac perfume.

Reseda odorata vars. *gigantea, grandiflora, pyramidalis* (Resedaceae). Mignonette. Up to 20 tons annually before 1914; eight tons in 1927; a few hundred kilograms in 1939.

Viola odorata (Violaceae). Two varieties of this species, formerly the Parma violet, today principally the Victoria violet, are used. In 1900 nearly 200 tons of flowers were treated, in addition to about 100 tons of the leaves. Cultivation is generally under olive trees.

Plant resinoids (there are also animal resinoids) manufactured from resins, gums and gum-resins obtained from plants by alcoholic or other extraction and used in perfumery or considered as possibly suitable for such use are discussed under the following heads, being obtained in addition to any other products mentioned.

AMBRETTE SEED, ABELMOSK SEED. *Hibiscus Abelmoschus* (Malvaceae). Steam distillation, generally carried out in Europe with seeds from Java, the Seychelles or Martinique, gives a musky oil; extraction yields a resinoid.

BALSAM RESINOIDS. Balsam of Peru is an exuded, viscous, dark brown or reddish brown resin used in perfumery and medicine and obtained from *Myroxylon Pereirae* (Papilionaceae), principally from San Salvador. Balsam of Tolu, brownish to reddish brown, comes from *M. balsamum* of South America. Styrax is obtained in Asia Minor by boiling in water and then expressing the bark of *Liquidambar orientalis* (Hamamelidaceae). The alcoholic resinoid is the purified styrax of pharmacopoeias.

BENZOIN. There are two principal types of this product, the Siamese from *Styrax tonkinense* (Styracaceae), a tree of Siam, and the Sumatra from *S. Benzoin* of Sumatra.

COSTUS. The root of costus, *Saussurea Lappa* (Compositae), is a source in India of resinoids highly valued in perfumery.

COUMARIN-CONTAINING PLANTS. The leaves of lacinaria and melilot and the seeds of tonka are sources of coumarin. The first, from *Liatris odoratissima* (Compositae), known also as deer's tongue and hound's tongue, are gathered from North Carolina to Florida and are used for perfuming tobacco. They acquire an odor of coumarin and vanilla only when dry, and are exported to Europe to be extracted there for their resinoids. They long served as raw material for the production of coumarin before synthetic manufacture of it. The dry flowers of several species of *Melilotus* (Papilionaceae) are treated for perfumery. Tonka beans are the seeds of the trees *Dipteryx odorata, D. oppositifolia* and *D. pteropus* (Papilionaceae) of Venezuela, the Guianas and northern Brazil. The seeds, after removal from their shells, are dried in the shade and then immersed in 65% alcohol for a half day. The alcohol is then poured off and the beans left to dry for five or six days in the shade, during which time they acquire a "frost" of coumarin crystals. Venezuelan beans, known as "Angostura", are the most highly valued. Not the source of Angostura bitters.

FENUGREEK. The yellowish seeds of fenugreek, *Trigonella Foenum-graecum* (Fabaceae), gathered in India, Arabia and Greece, yield extracts used in America in connection with vanilla and coffee extracts and in numerous tobacco flavors. Deodorized, they have therapeutic use.

HENNA. This dyestuff, important in Oriental and Arab cosmetics, is obtained from the leaves and roots of *Lawsonia inermis* (Lythraceae), cultivated in Arabia, Persia, India and Ceylon. The dried flowers yield a resinoid.

LABDANUM. From species of *Cistus*. "The Cretan gum-resin is today hardly more than a picturesque memory; on the other hand, the Spanish product is today still on the market, 15 to 20 tons being produced annually, of which 12 to 15 tons are from the province of Zamora.

"In Spain, the summits of the cistus are gathered in the off-season of the agricultural workers, and they are then dried in the sun. The branches, tied in small bundles, are immersed in boiling water, and a dark resin gathers and comes to the surface. It is decanted and as great a quantity as possible of the water is expressed from it. It is then moulded into blocks of about 10 kg. each, and the water continues to evaporate, while the resin hardens and becomse porous".

OAKMOSS. Commercial supplies consist primarily of the lichens *Evernia prunastri* and *E. furfuracea* with additions of *Sticta pulmonacea, Usnea ceratina, Ramalina farinacea, R. fraxinae, R. pollinaria* and species of *Alectoria* and *Parmelia*. They are gathered in various parts of Europe. Extraction is conducted in Grasse, Yugoslavia and Bulgaria. Lichens are always extracted after desiccation, for their perfume develops during storage. "The benzene resinoids are consumed in great quantities by the soapmakers, who use them either as such or partially decolorized, finding value in their strong odorant power and in their fixative qualities".

ORRIS. For perfumery the dried rhizomes of *Iris pallida, I. florentina* and *I. germanica,* cultivated around Grasse, and near Verona and Florence in Italy, are treated by steam distillation or extraction. Fresh rhizomes have practically no odor; the aroma develops only after months of storage.

PATCHOULI. Distillation of the leaves of *Pogostemon Cablin* (Labiatae) gives Singapore oil of patchouli. The extracted resinoid is used by perfumers and soapmakers. In Java and Sumatra the leaves of *P. Heyneanus* yield an inferior oil.

RESINS AND GUM RESINS. Under this heading there are described elemi from Manila elemi, *Canarium luzonicum* (Balsaminaceae), produced in the Philippines; galbanum from *Ferula galbaniflua, F. rubricaulis, F. erubescens, F. gummosa,* and *F. Schair* (Umbelliferae) of Persia and Asia Minor; mastic from *Pistacia Lentiscus* (Anacardiaceae) of Mediterranean and the Canary Islands; bitter or male myrrh from *Commiphora Myrrha* (Burseraceae) of Somaliland and southeastern Arabia; bisabol or female myrrh from *C. Kataf;* opopanax chiefly from *Opopanax Chironium* (Umbelliferae) of Persia; olibanum, or frankincense, from *Boswellia Carteri* of Somaliland and Arabia, *B. Frereana* and *B. Bhaw Dajiana* of Somaliland (Balsaminaceae).

SAFFRON. This red coloring substance is obtained from the stigmas of *Crocus sativus* (Iridaceae), an herb cultivated in France, Spain, Bavaria, Austria and Turkey. The flowers bloom in September and October for about three weeks and are gathered daily, early in the morning. The next day the stigmas are removed and dried over charcoal fires. About 15,000 blossoms are needed to produce one kilogram of fresh saffron, and preparation then reduces this weight to a fifth. Ten kilograms of prepared saffron may be obtained per hectare under cultivation. Steam distillation gives a small quantity of an essential oil that has been little studied. Extraction gives resinoids of value in the manufacture of liquors, food products and perfumes.